
Centrifuge Facility Conceptual System Study Volume I: Facility Overview and Habitats

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October 1990



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(NASA-TX-102860) CENTRIFUGE FACILITY
CONCEPTUAL SYSTEM STUDY. VOLUME I: FACILITY
OVERVIEW AND HABITATS (NASA) 352 pCSOL 06C

N91-19565

Unclass

65/51 0133440

NASA Technical Memorandum 102860

Centrifuge Facility Conceptual System Study

Volume I: Facility Overview and Habitats

October 1990

NASA
National Aeronautics and
Space Administration

PREFACE

This report presents the results of the Centrifuge Facility Conceptual System Study conducted from mid 1987 through mid 1989. The main body of the report consists primarily of charts presented at the study review held at NASA Ames Research Center (ARC) on August 17 and 18, 1989. The charts have been revised to reflect the results of that review. Explanations for the charts are provided on the adjacent pages.

The Centrifuge Facility (Facility) is the major element of the biological research facility for the implementation of NASA's Life Science Research Program on Space Station Freedom using non-human specimens (small primates, rodents, plants, insects, cell tissues, etc.). The Facility consists of a variable gravity Centrifuge to provide artificial gravity up to 2 earth g's, a Holding System(s) to maintain specimens at micro-gravity levels, a Glovebox, and a Service Unit for servicing specimen chambers.

The initial study focused on a Centrifuge Facility for the Space Station Freedom (Freedom) U.S. Laboratory Module. Subsequently, in response to a programmatic decision to move the Centrifuge out of the U.S. Laboratory, a study was conducted to define a concept for a Centrifuge to be located in the end cone of a Node or separate module. The results of that study, although not part of the August 1989 review, are included in this report for completeness. The work reported herein is based on the Freedom configuration and capabilities prior to the program changes which occurred in late 1989. No attempt has been made to reflect the impact of these changes on the Centrifuge Facility as described herein.

This report is being issued in three volumes. Volume I & II describe the systems for the initial study divided as described below.

Volume I contains chapters 1-4. These are:

- 1) System Study Overview;
- 2) Rat Habitat;
- 3) Squirrel Monkey Habitat;
- 4) Plant Habitat

Volume II contains chapters 5-9. These are:

- 5) Holding System;
- 6) Centrifuge System;
- 7) Glovebox System;
- 8) Service System;
- 9) System Study Summary

Volume III contains the Centrifuge System - Node Accommodations Study Results.

The study and report here presented are the result of a team effort. The members of the team with primary responsibility for the contents of this report were:

| | | | |
|----------------------|-----------------|-----------------|--------------------|
| Patricia Blair | Mike Guerrero | Frank Nguyen | Linda Swan |
| Alan Cartledge | Peter Haddeland | Marc Murbach | Robert Synnestvedt |
| Jorge Garces-Porcile | Mike Horkachuck | Richard Schaupp | Mark Turner |
| Vladimir Garin | Ulrich Kuebler | Sidney Sun | Will Vallotton |

Other members of the Biological Research Project Office at NASA Ames Research Center, including support service contractors, provided support as required to the study effort.

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ABBREVIATIONS AND ACRONYMS

| | |
|------|--|
| ARC | Ames Research Center |
| BW | Black And White |
| CC/S | Cubic Centimeters Per Second |
| CCW | Counter Clockwise |
| CF | Centrifuge Facility |
| CFM | Cubic Feet Per Minute |
| CFU | Colony Forming Units |
| CRS | Contaminant Removal System |
| CW | Clockwise |
| DMS | Data Management System |
| ECLS | Environmental Control and Life Support |
| ECS | Environmental Control System |
| EDP | Embedded Data Processor |
| HEPA | High Efficiency Particulate Air Filter |
| HX | Heat Exchanger |
| IR | Infrared |
| LED | Light Emitting Diode |
| LSE | Laboratory Support Equipment |
| LSG | Life Science Glovebox |
| MDM | Multiplexer de-Multiplexer |
| NIH | National Institute of Health |

ABBREVIATIONS AND ACRONYMS

| | |
|-----------|---|
| NIU | Network Interface Unit |
| PMMS | Process Materials Management System |
| PPA | Power Protection Assembly |
| QD | Quick Disconnect |
| RAHF | Research Animal Holding Facility |
| RFP | Request For Proposal |
| RH | Relative Humidity |
| SCSU | Specimen Chamber Service Unit |
| SM | Squirrel Monkey |
| SMAC | Space Maximum Allowable Concentration |
| S. S. F. | Space Station Freedom |
| SWG | Science Working Group |
| TBD | To Be Determined |
| TCCS | Trace Contaminant Control System |
| TIMES | Thermoelectric Integrated Membrane System |
| U. S. Lab | U. S. Laboratory Module |
| UV | Ultraviolet |
| VCDS | Vapor Compression Distillation System |

CENTRIFUGE FACILITY SYSTEMS STUDY

Chapter 1

System Study Overview

OUTLINE

The facing page outlines the contents in this chapter of the study report.

OUTLINE

- Introduction
- Study Objectives
- Study Approach
- Study Guidelines
- Primary Requirements
- Study Fidelity
- Systems Preview
- Facility Tradeoffs
- Conclusions
- Appendix

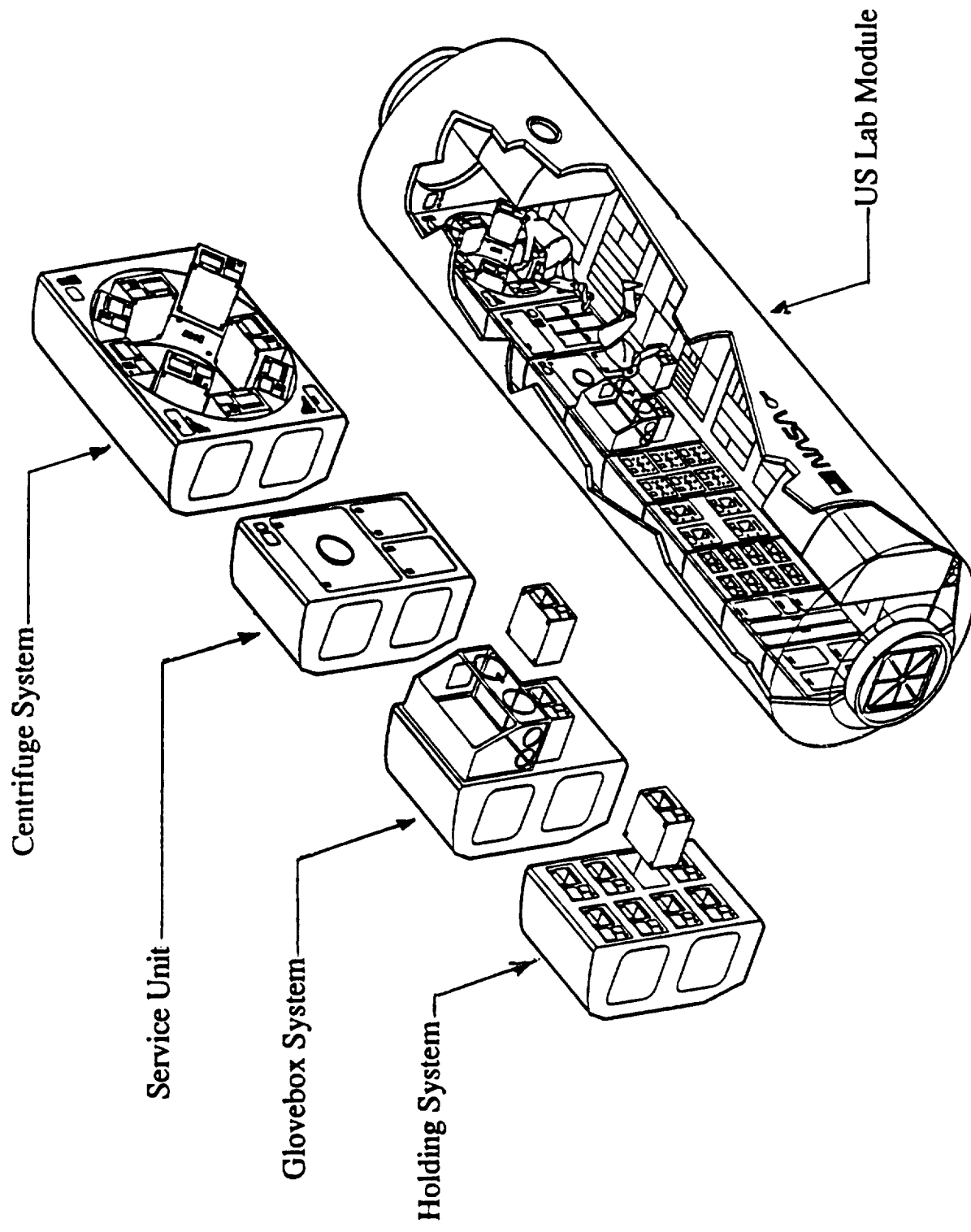
INTRODUCTION

The Centrifuge Facility, also referred to as the Facility, will provide the nucleus of a long term biological research laboratory designed for research in non-human life sciences in Space Station Freedom. The Facility will be designed to accommodate basic research in gravitational biology, radiation effects on living organisms, aspects of closed environmental life support and other research activities including behavior, nutrition and metabolic studies.

Five basic systems are to comprise the Facility core. **Habitats** are modular units which house living specimens. For this study, only plants and animals are considered. However it is anticipated that in the future, habitats will be designed to accommodate other specimens such as cells, tissues, and insects. A **Holding Unit** supports and supplies resources to various combinations of habitats in micro-gravity. A **Centrifuge** supports and supplies resources to various combinations of habitats on a rotor which centripetally accelerates the habitats to simulate gravitational acceleration. A **Glovebox** is used to conduct experimental procedures with the specimens and as a system in which to perform service operations for the Facility. A **Service Unit** is used to replace or clean some of the serviceable items within the Facility such as specimen chambers within the habitats.

The figure on the facing page illustrates the Centrifuge Facility mounted in the U.S. Laboratory of Space Station Freedom, the configuration for the initial study. An alternative mounting for the Centrifuge System in the end cone of a Freedom Node is described in Volume III of this report.

INTRODUCTION



STUDY OBJECTIVES

The primary objective of this study was to define a Centrifuge Facility design concept which satisfies the mission requirements to the extent practical within Freedom and other programmatic constraints. Pursuing this objective identified system interactions, critical design features, problematic system requirements, and technology requirements necessary to meet the design objectives. From these, a set of baseline system characteristics is to be defined.

Other objectives of this study were to assess the design impacts of science requirements provided by the Science Working Group (SWG), to better prepare ARC project office personnel for subsequent program management, and to develop analysis tools for monitoring contracted Facility development. The current study will serve as a building block for subsequent studies and should provide information for the contractors at the start of Phase B (system definition) and C/D (design, development, test of the flight facility) of the project development.

It should be noted that the actual flight Facility will be designed and built by a system contractor. The characteristics reported herein should only be considered as representative, and the Freedom program should continue to use Facility system characteristics supplied through formal channels, not the data in this report.

STUDY OBJECTIVES

- Define baseline conceptual design for integrated Facility System
 - Satisfy mission requirements to the extent practical
 - Identify system interactions and design impacts
 - Identify hard to meet, conflicting and vague requirements
 - Identify technology requirements
 - Define candidate Facility characteristics for Freedom program
- Prepare project personnel for subsequent program management
 - Understand design impacts from system and science requirements
 - Develop analysis tools for monitoring facility design, development and test
- Provide building block for subsequent study efforts
 - Identify additional work required

SYSTEM STUDY APPROACH

Many Facility variations must be examined to assess the design impacts of accommodating the Facility in space. To divide these efforts into manageable portions, the study was divided into phases.

The first phase of the system study examines a Facility located in the S. S. Freedom U. S. Laboratory Module. The guidelines used in this phase are described in subsequent pages. Subsequent study phases will examine alternate locations within Freedom (i.e. nodes) and the Spacelab*. Also, the feasibility of designing a larger centrifuge to fit within a Freedom Node or end mounted to the Spacelab will be determined. Separate reports will be written to document the subsequent study efforts.

This report covers the Facility designed for the Freedom U. S. Lab. Module (U.S. Lab).

Note: Subsequent to the completion of this phase of the study, NASA decisions have reduced the likelihood of using Facility hardware for Spacelab missions. Therefore, study efforts relative to that option have been dropped.

* Accommodation of the Centrifuge System in a Freedom Node is described in Volume III of this report. Due to programmatic changes no further in-house work is planned for Spacelab accommodation.

SYSTEM STUDY APPROACH

- Phased Study
- Phase I: Facility located in Space Station Freedom U.S. Lab
- Subsequent Phases
 - Large Centrifuge (2.3 - 2.6 meter dia.) in Freedom Node
 - Spacelab Accommodation
 - Top level study with MSFC completed 5/89 - detailed examination remains to be done
 - End Bell Mount for Centrifuge (2.3 - 2.5 meter dia.)
 - Spacelab racks

STUDY GUIDELINES

To gain an understanding of the problems to be faced by the Phase B system contractors, the current designs are based on the phase B study specifications, Freedom specifications and science requirements. Specifications for the 74.5" Freedom standard racks were used as guidelines to provide volume constraints and resource interfaces for the Facility systems. Fitting within 74.5" racks provides additional flexibility for the Facility mounting locations.

Only the major Facility systems and habitats for the major classes of experiments were considered; other Facility elements such as support equipment will be considered in subsequent efforts.

All Facility designs were developed to at least the conceptual level with appropriate consideration of system interactions. As a minimum, point designs with limited tradeoffs were developed. The Facility systems satisfied system and science requirements to the extent practical; the rationale for compromising the requirements were documented.

STUDY GUIDELINES

- Design for Freedom US Lab
- Use Freedom 74.5" standard racks with standard interfaces
- Base designs on phase B specifications; comply with:
 - Level II Science Requirements Document
 - Freedom/Spacelab requirements
 - Animal welfare requirements
- Consider major Facility elements
 - Systems: Centrifuge, Holding Unit, Glovebox, Service Unit
 - Habitats: Rodent, Squirrel Monkey, Plant
- Develop conceptual designs
 - Consider system interactions
 - Develop point designs with limited tradeoffs
- Satisfy system and science requirements
 - Document rationale for not meeting requirements

PRIMARY REQUIREMENTS

The primary system requirements are listed on the next few pages. These are the requirements which had the greatest impact on the Facility design. Detailed requirements for each of the systems and the habitats are provided in respective chapters of the report.

System designs were based on 74.5" standard Space Station racks. This basis provides the most options for locating the Facility systems within the Space Station and imposes volume constraints on the system designs. As a further constraint, each system was limited to fit within one double rack, with the exception of the Centrifuge which was limited to two double racks.

If available, specifications for subsystems were to be based upon equipment which has already been designed. Stated another way, the development of new technologies to meet the Facility objectives was limited.

Commonality and interchangeability reduce the variance in spare units and components, hence reducing the logistics requirements and costs. Therefore, the Facility should be comprised of systems and subsystems with common components. Furthermore, these components must be easy to service to reduce the dependence on Freedom resources and crew operations.

As the Space Station is to be used for micro gravity research, there are stringent requirements regarding permissible dynamic disturbances from payloads. Moreover, the life science requirements mandate reduced disturbances to specimens. As a primary requirement, all systems within the Facility are to limit the dynamic disturbances to specimens and to Freedom.

PRIMARY REQUIREMENTS

- Comply with Freedom interface requirements and constraints
- Satisfy human factors and safety requirements
- Base designs on standard 74.5" double rack
 - Centrifuge: 2 std racks
 - Other systems: 1 std rack
- Use proven designs and technology
- Design for commonality and interchangeability
- Design for easy maintenance and operation
- Limit dependence on Freedom resources and crew time
- Limit dynamic disturbances to Freedom and Specimens

PRIMARY REQUIREMENTS (CONT'D)

A design objective for the Facility is to accommodate a variety of specimen types. The initial study focused on rats, squirrel monkeys, and plants; these are expected to be a subset of the specimen types used in experiments to be conducted over the life of the program. Although a particular mission interval may be dedicated to a specific specimen or experiment type, the capability to accommodate multiple specimen types simultaneously offers flexibility to the experimenters. Furthermore, it is anticipated that such flexibility will save crew time between experiment intervals, as no hardware changes would be required to retrofit the Facility.

The Facility must be capable of on-orbit assembly and integration into Freedom. Also, after operations have begun, the Facility must be capable of operation for 90 days and have reserve for a 45 day contingency without resupply from ground.

To facilitate the simultaneous accommodation of multiple specimen types, there must be a common interface between habitats and systems. This will allow any habitat to fit within any habitat mounting location in any system.

The systems are to provide resources in a manner which does not add undue stress to the specimens. This includes the operational ability to access the specimens and the ability to clean hardware components which have been contaminated. Also, the subsystems within the Facility must provide sufficient redundancy to prevent a condition which threatens specimen life in the event of a single failure.

PRIMARY REQUIREMENTS (CONT'D)

- Accommodate a variety of specimen types
 - Initially plant, rodent, and primate experiments
 - Accommodate multiple specimen types simultaneously
 - Provide margin for growth experiments
- Accommodate on-orbit assembly and integration
- Operate without resupply for 90 days plus 50% contingency
- Habitats interchangeable between mounting locations
- Provide stress free environment for specimens
- No single failure to threaten life of specimens
- Satisfy specimen access requirements
- Provide capability to clean or replace contaminated hardware

PRIMARY REQUIREMENTS (CONT'D)

Achieving the appropriate number of levels of bioisolation and controlling contamination are important requirements. The Facility must be isolated from the crew such that there is no cross-contamination between the crew and the specimens. Furthermore, contaminated hardware must be isolated from the crew and the specimens, and specimens in one habitat must be isolated from specimens in another habitat.

The most difficult requirement to satisfy is the achievement of the required number of levels of bioisolation during servicing and maintenance; further work is required to better understand this aspect of the system design.

PRIMARY REQUIREMENTS (CONT'D)

- Control bioisolation and cross-contamination during all operations
 - Concerned about crew/specimen, specimen/specimen, and hardware/specimen contamination
 - Two levels of bioisolation required for biological elements for all normal operations and storage
 - Triple containment required for hazardous (toxic) materials

STUDY FIDELITY

The current system study depth and fidelity is equivalent to a NASA Phase A Conceptual Design Study. Designs are based on first order analyses. Component characteristics were derived from catalogue entries, from information about similar equipment in existing programs, and from estimates.

STUDY FIDELITY

- Based on engineering judgement and first order analyses
 - Subsystems based on information about Freedom, existing equipment, catalogue entries, and estimates
- Performed simplified air flow analyses to size ducts
- No detailed thermal or stress analyses
- Contamination control system scaled from Spacelab
- Air-water separator and pumps scaled from Spacelab
- Rotary joint hardware based on ARC Centrifuge Mockup and catalog data

SYSTEM PREVIEW

The following pages contain an overview of each major Facility system. Detailed descriptions will be found for each system in respective chapters of this report.

SYSTEM PREVIEW

- Preview of selected baseline systems to follow
 - Rodent Habitat
 - Unrestrained Squirrel Monkey Habitat
 - Restrained Squirrel Monkey Habitat
 - Plant Habitat
 - Holding System
 - Centrifuge
 - Glovebox
 - Service Unit
- Detailed descriptions to follow later

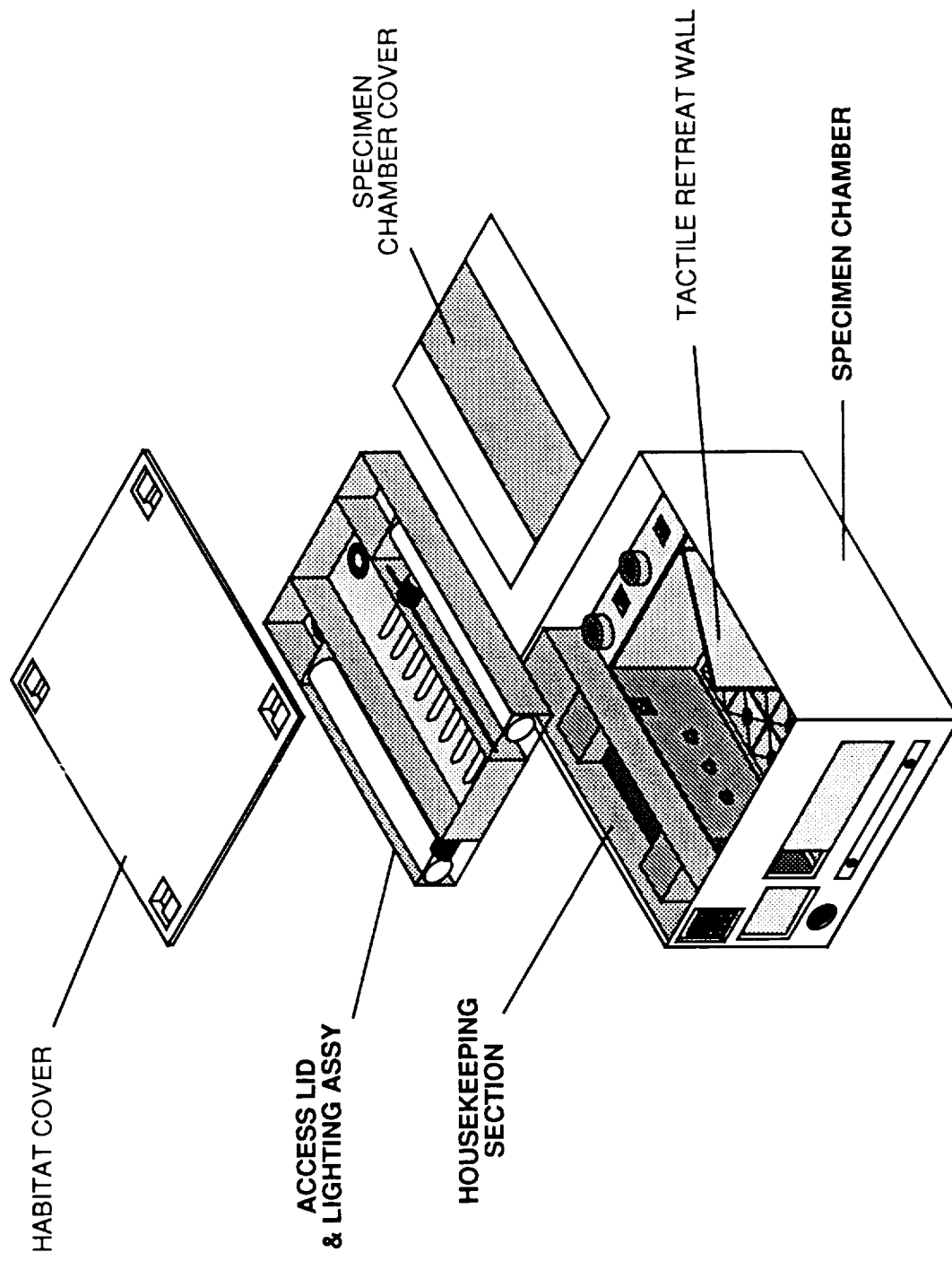
RODENT HABITAT

The Rodent Habitat is a modular unit with the following major sections: housekeeping section, access lid/lighting assembly, and removable specimen chamber with waste tray. An exploded view depicting these sections is presented on the facing page.

The housekeeping section contains electronics, food, and watering systems. The specimen chambers can be configured into individual or group living areas. To be serviced, the habitat must be removed from the Holding System or Centrifuge; electronics, food and watering systems are accessed through the Glovebox. Specimen access is through the top of the habitat after removing a lid. Respiration air and other resources are provided at the rear of the habitat via a standard interface plate.

The habitat external dimensions are 43cm wide x 51cm deep x 30cm high (17" x 20" x 12"). The specimen chamber has a volume of 26,700 cm³ (1,630 in³) and a floor area of 1,300 cm² (204 in²). The estimated mass of the habitat is 40 kg (88 lbs).

RODENT HABITAT



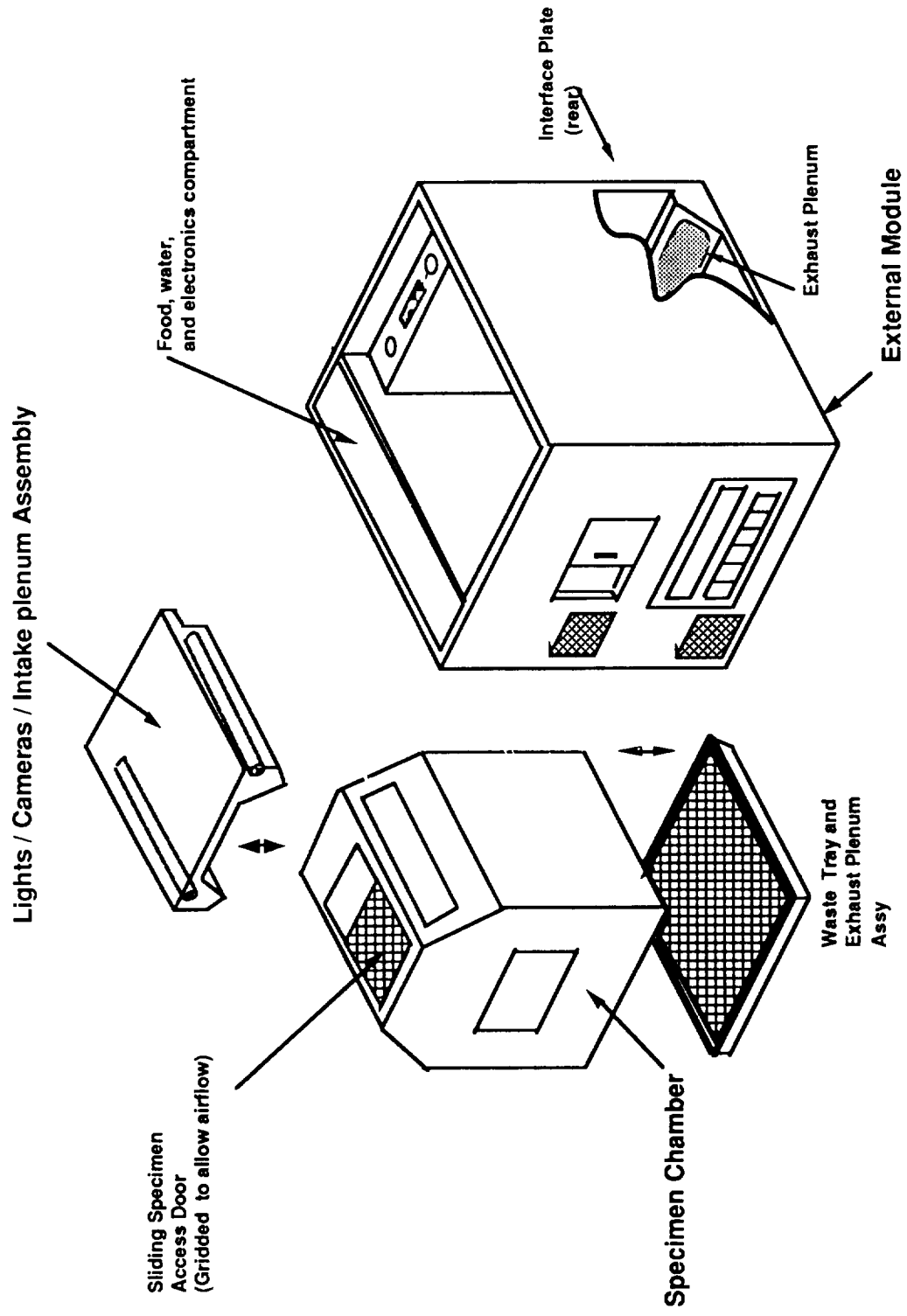
SQUIRREL MONKEY HABITAT - UNRESTRAINED

The Unrestrained Squirrel Monkey Habitat is a modular unit with the following major sections: external module, removable chamber with waste tray, and specimen chamber cover assembly. An exploded view depicting these sections is presented on the facing page.

The food, water and electronics systems are contained in a side compartment in the external module. To be serviced, the habitat must be removed from the Holding System or Centrifuge; electronics, food and watering systems are accessed through the Glovebox. Access to the squirrel monkey is through the top of the habitat after removing a lid. Respiration air and other resources are provided at the rear of the habitat via a standard interface plate.

The habitat external dimensions are 43cm wide x 51cm deep x 61cm high (17" x 20" x 24"). The specimen chamber has a floor area of 1,350 cm² (210 in²) and a maximum height of 47cm (18.5"). The estimated mass of the habitat is 73kg (160 lbs)

SQUIRREL MONKEY HABITAT - UNRESTRAINED



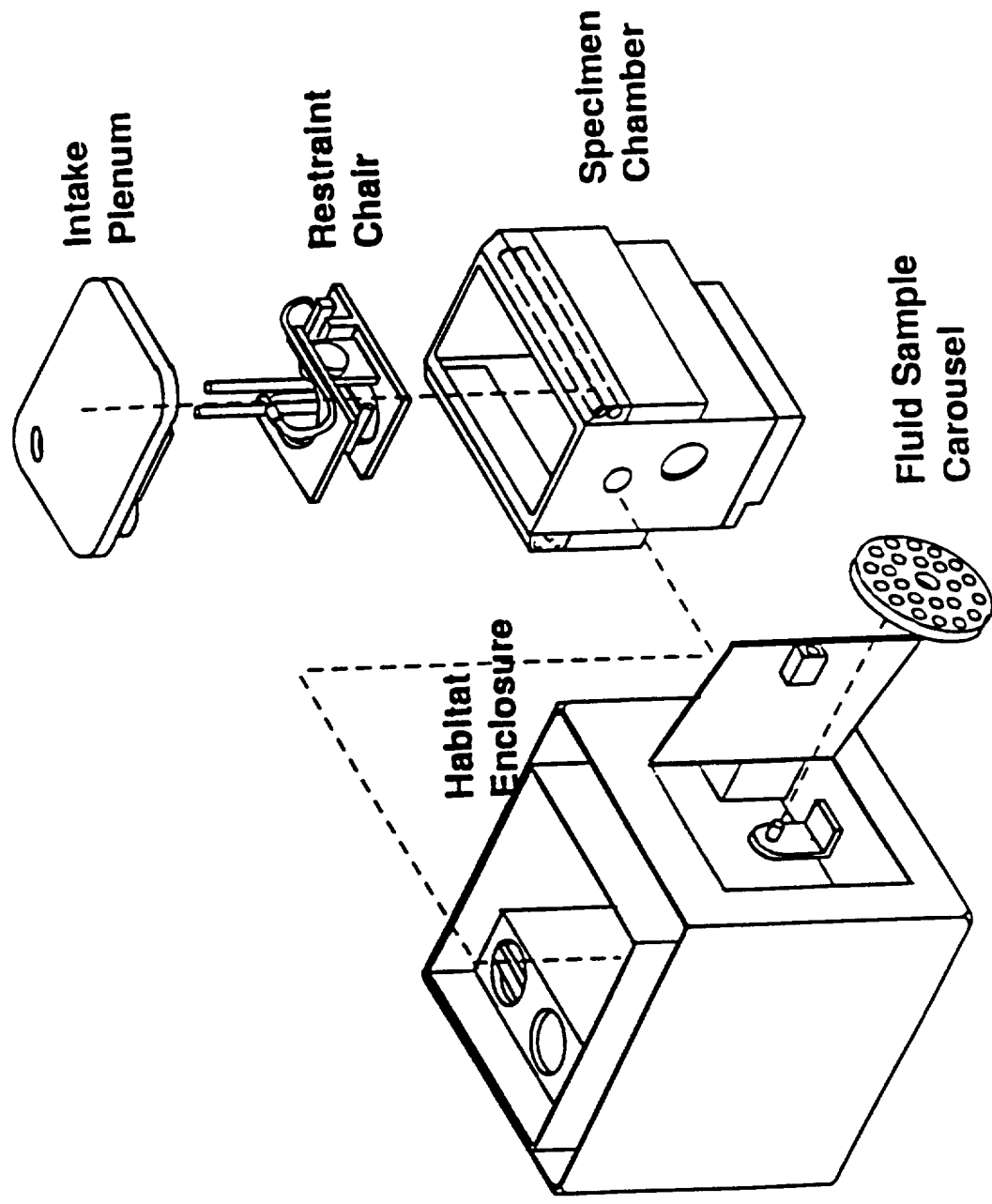
SQUIRREL MONKEY HABITAT - RESTRAINED

The Restrained Squirrel Monkey Habitat is a modular unit with the following major sections: external module, removable specimen chamber, and restraint chair mounted in specimen chamber. An exploded view depicting these sections is presented on the facing page.

Food and a video system are located in a side compartment in the external module. Similarly, the water and electronics are located in an aft compartment and a specimen fluid sampling unit is located in a forward compartment accessible from the front. An animal restraint chair is contained in the specimen chamber. To be serviced, the habitat must be at the Glovebox. Specimen access is through the top of the habitat after removing a lid. As the squirrel monkey is harnessed to the restraint chair, the chair must be removed from the specimen chamber to access the animal. Respiration air and other resources are provided at the rear of the habitat via a standard interface plate.

The habitat external dimensions are 43cm wide x 51cm deep x 48cm high (17" x 20" x 19"). The specimen chamber has 660cm² (104 in²) of floor area and a height of 33cm (13"). The estimated mass of the habitat is 61kg (135 lbs.)

SQUIRREL MONKEY HABITAT - RESTRAINED



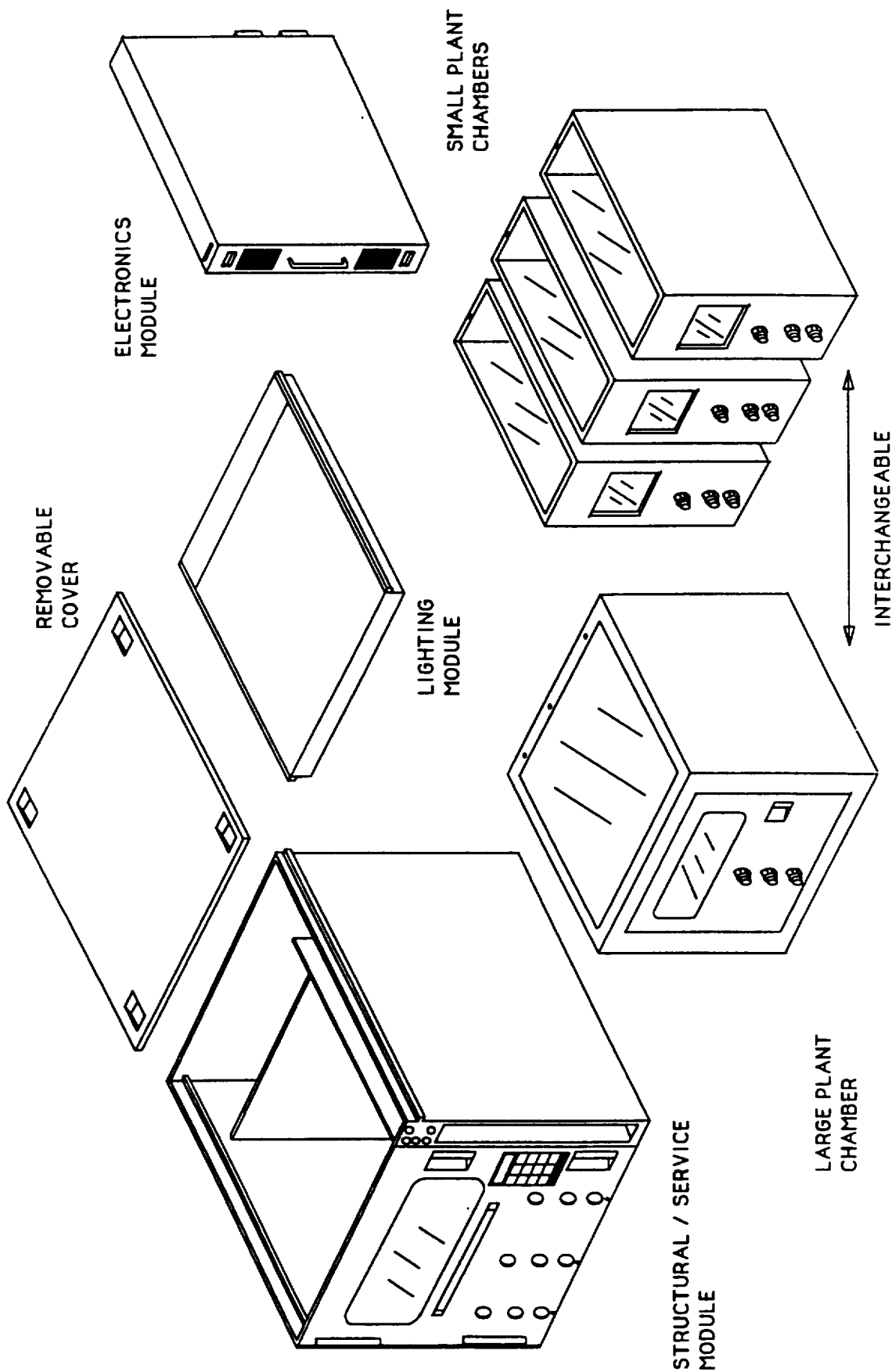
PLANT HABITAT

The Plant Habitat is a modular unit which is divided into the following major sections: structural module, plant growth chamber (large and small), lighting module, and electronics module. An exploded view depicting these sections is presented on the facing page.

The plant environmental control system is a semi-closed loop system within the habitat with gases (oxygen, nitrogen, carbon dioxide), coolant, distilled water, liquid/gaseous waste removal, and electrical resources provided via the standard interface plate located at the rear of the habitat. Components of the environmental control and nutrient delivery system are located in the aft section of the structural module. The lighting module uses LED arrays. The habitat accommodates either one large or three small plant growth chambers; each growth chamber has an adjustable root/shoot boundary. The plant growth chamber may be removed from the top of the habitat at the Glovebox or from the front when mounted in the Holding System or Centrifuge.

The habitat external dimensions are 43cm wide x 51cm deep x 48cm high (17" x 20" x 19"). The large plant growth chamber has 1,290 cm² (200 in²) floor area and a height of 38cm (15") available for plants. The small plant growth chambers each have 387cm² (60 in²) and 38cm (15") available for the plants. The estimated mass of the Plant Habitat is 55kg (120 lbs).

PLANT HABITAT



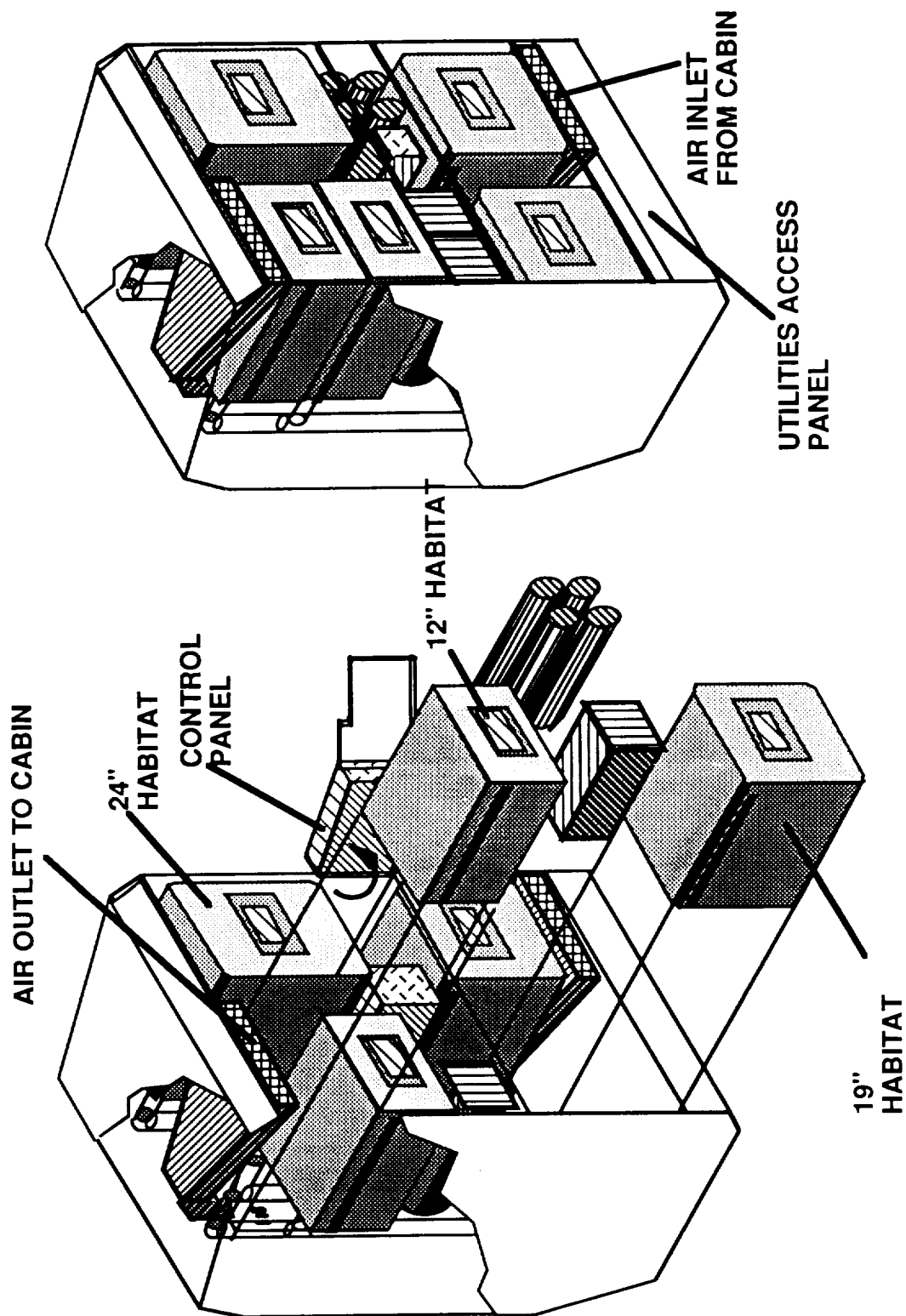
HOLDING SYSTEM

The Holding System fits within a standard S.S. Freedom 74.5" rack envelope. The drawing on the facing page depicts one arrangement of habitats in the Holding System.

The Holding Unit satisfies most science requirements. It contains 4 large cavities in which to support habitats. Each cavity can accept 1 medium (19" high) or 1 large (24" high) habitat or 2 small (12" high) habitats. The Holding Unit accommodates habitats for different specimen types simultaneously and provides a standard interface to each habitat. The Holding System uses a single pass environmental control system; air is extracted from the cabin, preconditioned prior to entering the habitat, passes through the habitats, passes through a contaminant removal system, and exhausts back to the cabin.

Most Holding System servicing can be performed from the front. However, some components which need infrequent servicing, require the rack to be tilted forward to provide access to components from the rear of the Holding System. Heat rejection is via a combination of liquid coolant, cabin air, and avionics air. Controls are located on a swing-out panel at rack mid level. At least 2 levels of bioisolation are maintained during operations. The estimated mass of the Holding Unit is 650kg (1400 lbs).

HOLDING SYSTEM



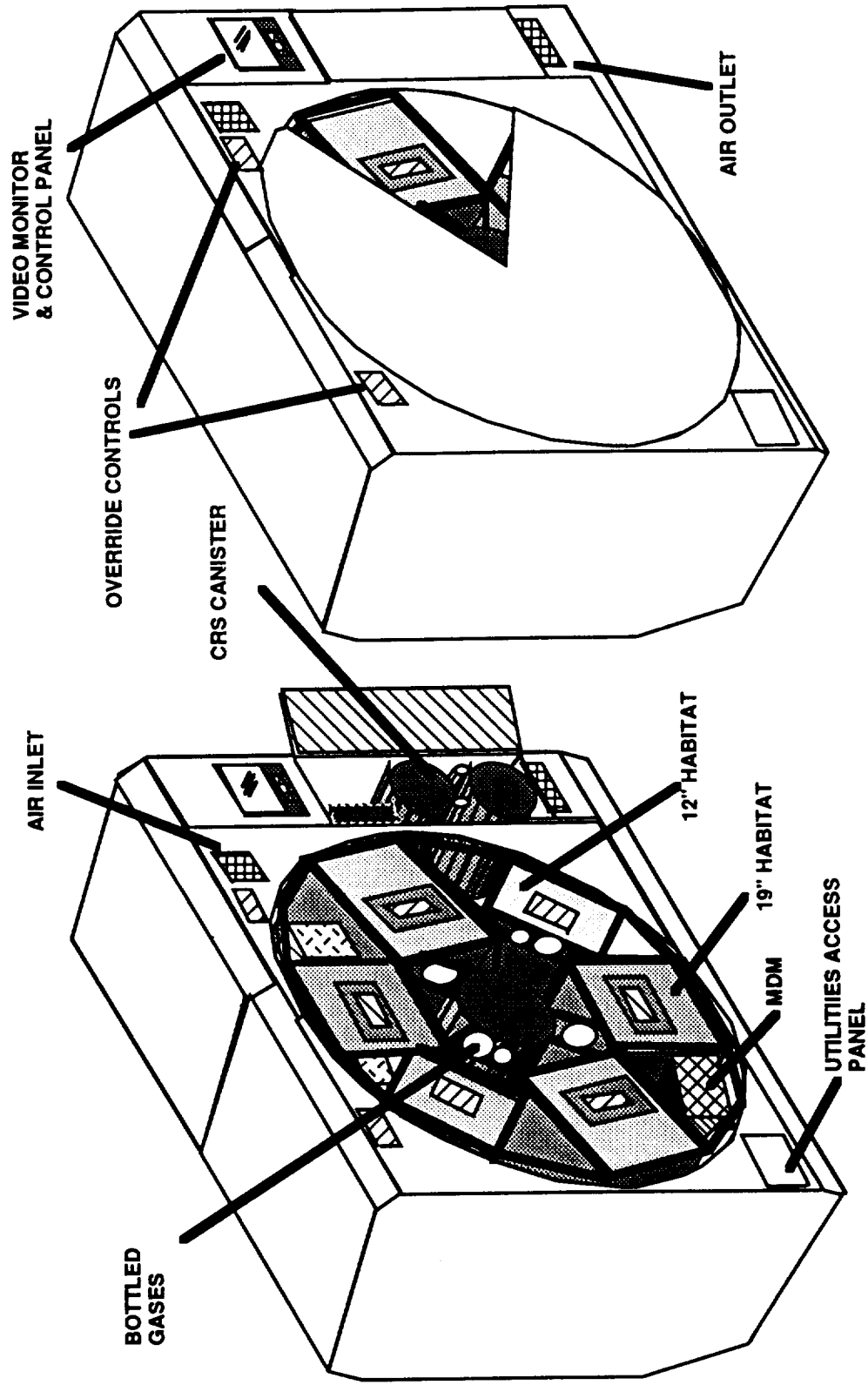
CENTRIFUGE SYSTEM

The Centrifuge System fits within 2 standard S.S. Freedom 74.5" rack envelopes. The drawing on the facing page depicts one arrangement of habitats in the Centrifuge.

The Centrifuge can be divided into sections for installation in Freedom. The Centrifuge has 4 medium (19" high) and 2 small (12" high) cavities for supporting habitats. Thus up to 6 small habitats can be accommodated.

The system satisfies most science requirements except the requirements for an automatic habitat extractor and the accommodation of the large (24" high) habitats. The large habitats and extractor could not be accommodated due to volume constraints in the 74.5" racks. The habitat interface accommodations, environmental control system design, heat rejection system design, and maintenance features are similar to the Holding Unit. A dynamic mass balancer is used to reduce disturbances transmitted to the habitats and S.S. Freedom. A counter momentum rotor is not incorporated in the baseline design. Orienting the Centrifuge rotational axis along the Freedom Y axis may be required to limit the net angular momentum of the Centrifuge relative to Freedom. Controls are located in the upper right hand corner. At least 2 levels of bioisolation are maintained during operation. The estimated mass of the Centrifuge is 1,300 kg (2800 lbs.)

CENTRIFUGE SYSTEM



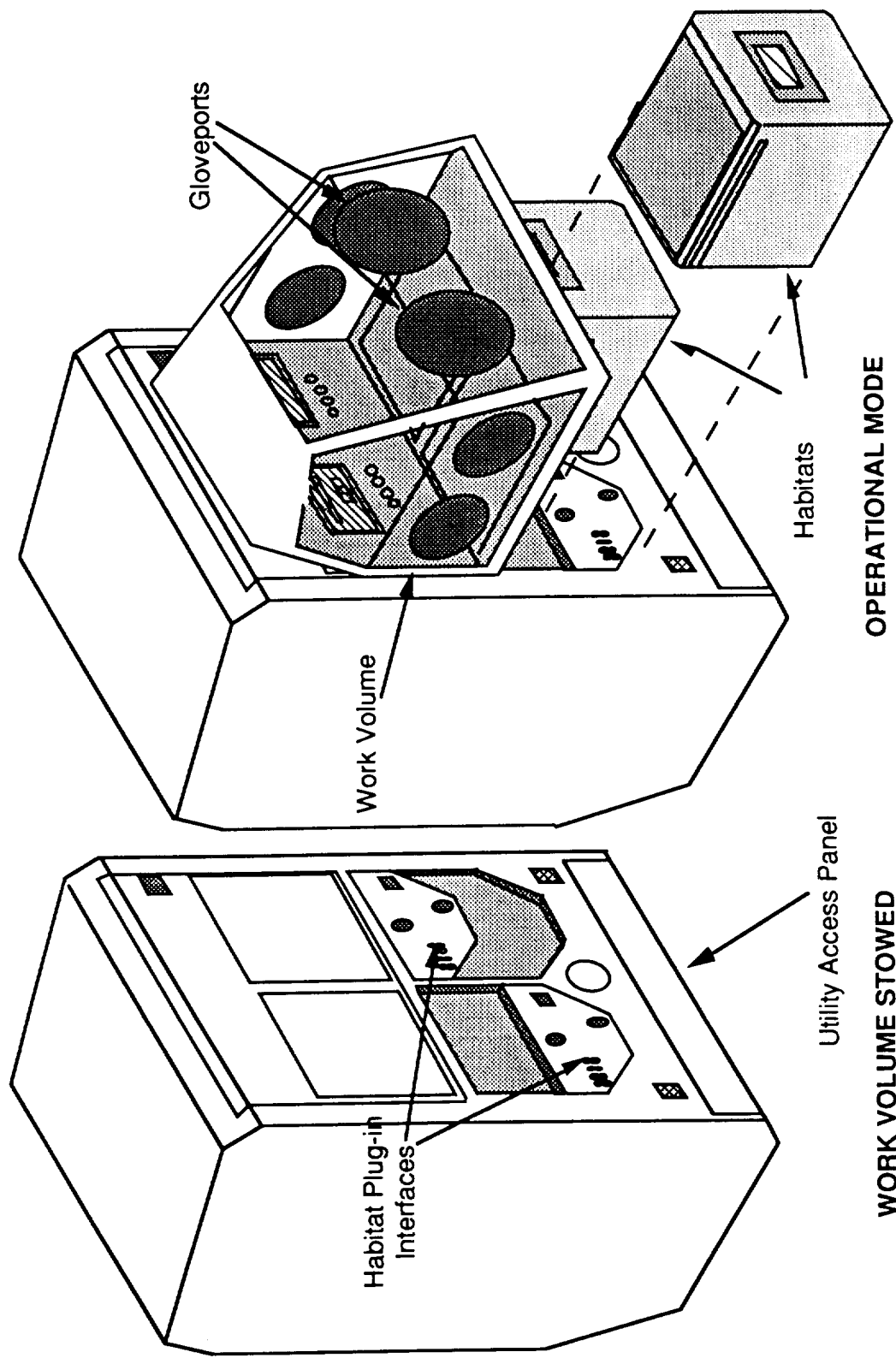
GLOVEBOX SYSTEM

The Glovebox fits within a standard S. S. Freedom 74.5" rack envelope. The drawing on the facing page depicts one arrangement of habitats attached to the Glovebox.

A hinged class III fully contained work volume with 6 gloveports provides access for 2 pair of hands. The work volume stows inside the rack when not in use. The Glovebox accommodates 2 habitats or 2 equipment modules for transferring Lab Support Equipment (LSE) to the work volume. Access to these habitats or equipment modules is through doors in the floor of the work volume. Both gloves and trash bags can be attached to gloveports.

Video display and control panels are located inside the work volume; control panels are also located outside the glovebox. Utility access for LSE and standard user services (vacuum, compressed nitrogen, water) are provided inside the work volume. Inlet air to the work volume is conditioned through HEPA filters and is processed to remove contaminants before being exhausted to the cabin. Servicing of expendables is from the front of the rack. Heat rejection is via liquid coolant, cabin air, and avionics air. At least 2 levels of bioisolation are maintained during operation. The estimated mass of the system is 450kg (1000 lbs.).

GLOVEBOX SYSTEM

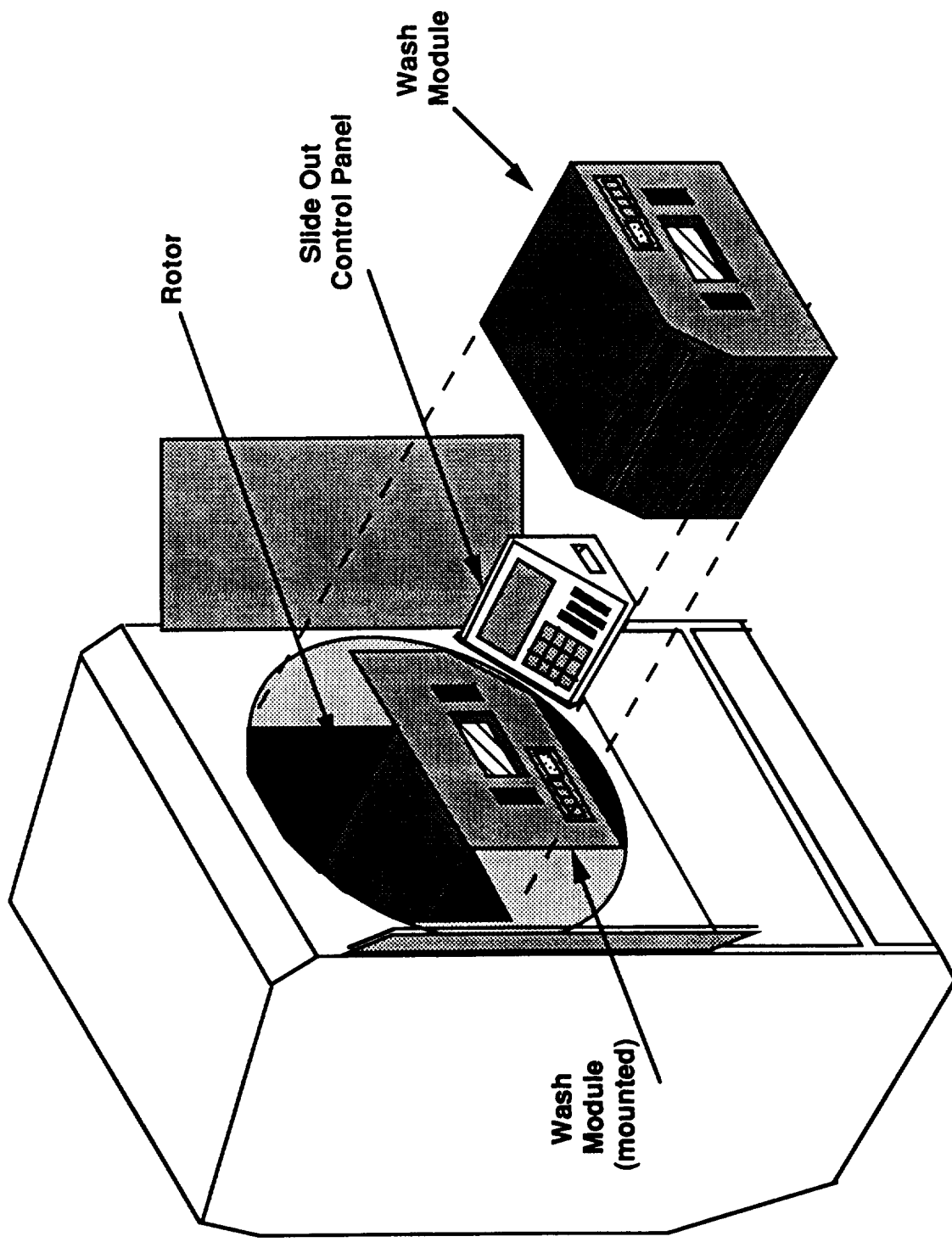


SERVICE UNIT

The Service Unit fits within a standard S.S. Freedom 74.5" rack envelope. The drawing on the facing page depicts the baseline concept for a Service Unit.

The baseline concept chosen for obtaining clean specimen chambers is a hot water and detergent washer which uses 2 wash modules. Dirty specimen chambers are placed in the wash modules at the Glovebox, then carried to the Service Unit and inserted into a rotating drum. Cleaning takes place entirely within the wash modules. Each wash module can accommodate 1 large or 1 medium or 2 small habitat specimen chambers. Wash water is recycled for reuse to conserve resources. Preheating the water and washing takes about 5 hours, recycling water takes about 12 hours for a total cycle time of 17 hours. Washer control is via a slide out control panel on the front of the unit. Expendable items are accessed from the front of the rack. Heat rejection is via liquid coolant, cabin air, and avionics air. The estimated mass of the Service Unit is 450kg (1000 lbs.).

SERVICE UNIT



FACILITY TRADEOFFS

Many tradeoffs were performed to develop the concepts presented in this report. Some of these tradeoffs affected all of the Facility systems and habitats and others affected only individual systems and habitats. The following pages will address the Facility tradeoffs which affected all of the Facility systems. An outline of these tradeoffs is presented on the facing page.

FACILITY TRADEOFFS

- Habitat Configuration
- Specimen Chamber Servicing (Washing vs Replacement)
- Division of Functions
- Air Flow (Single Pass vs Recirculating system)
- System Air Flow Rates
- Temperature/Humidity Control
- On-Orbit Transport of Habitats

HABITAT CONFIGURATION

The adjacent page lists some of the requirements which influenced the choice of the habitat configurations.

The habitats must satisfy rack envelope constraints, provide sufficient volume for specimens, accommodate the required number of specimens, and be compatible with the Glovebox and potential logistics systems. Habitats for some specimen types, such as seeds and lower life forms, may be used to carry the experiments to space thus eliminating the respective need for unique logistics systems.

The Facility requirements for specimen accommodation within each habitat and for sizes of respective specimen chambers are also shown on the adjacent page. These requirements are assumed to be self-explanatory.

HABITAT CONFIGURATION

- Constrained by geometry, specimen sizes and types, Glovebox operations, and logistics
- Accommodate ≥ 4 plant or primate or ≥ 6 rodent habitats on Holding System and Centrifuge and 2 habitats on Glovebox
- Satisfy specimen accommodation requirements in habitats
 - Rodents ≥ 6 rats/habitat, ≥ 12 mice/habitat
 - Primates ≥ 1 animal/habitat
 - Plants ≥ 200 in² growing area/habitat
- Height of habitat specimen chambers:
 - Rodents $\geq 5''$ for mice; $\geq 6''$ for rats
 - Primates $\geq 12''$ for restrained squirrel monkey; $\geq 18''$ for unrestrained squirrel monkey
 - Plants $\geq 15''$ for combined root/shoot zones

HABITAT CONFIGURATION (CONT'D)

Additional factors which influence the habitat configurations are listed on the facing page.

Since Freedom is to provide a long duration research facility in space, and experiments will evolve, the Facility must be able to evolve as well. Thus some margin for growth experiments should be considered in selection of habitat sizes (i.e. metabolic or breeding experiments). Other requirements are to develop habitats which are interchangeable within the systems and systems which accommodate mixed habitats. This implies developing standard mounting cavity sizes and interfaces for the habitats at the Holding System, Centrifuge and Glovebox. In this way, habitats can be modified for future experiments while the systems provide standard resources.

Although the Facility concept presented here uses standard mounting cavity sizes and interfaces, it uses more than one habitat size. The rationale for this is described on subsequent pages.

HABITAT CONFIGURATION (CONT'D)

- Provide capability for Facility and experiments to evolve
- Habitats must be interchangeable in their various mounting locations
- Accommodate mixed habitats in Holding System and Centrifuge
- Limit number of habitat sizes

SELECTION OF HABITAT SIZES

The facing page shows the rationale for the habitat sizes selected for the baseline design.

Habitats dimensioned to fit in a standard 1/2 rack could be carried both in Freedom racks and in the STS middeck lockers, should that option be selected for logistics. Thus, all habitats have a common width and depth of 43cm (17") and 51cm (20") respectively, which permits the habitats to fit in standard racks.

Since the height requirements varied substantially for each specimen type, more than one habitat height was required. Three heights were selected; 48cm (19"), 60cm (24") and 30cm (12"). These heights satisfied the minimum height requirements specified for each specimen type. Furthermore, the 48cm (19") height fits within a double STS middeck locker.

Since habitats must be interchangeable between mounting locations, a standard interface is required for all habitats.

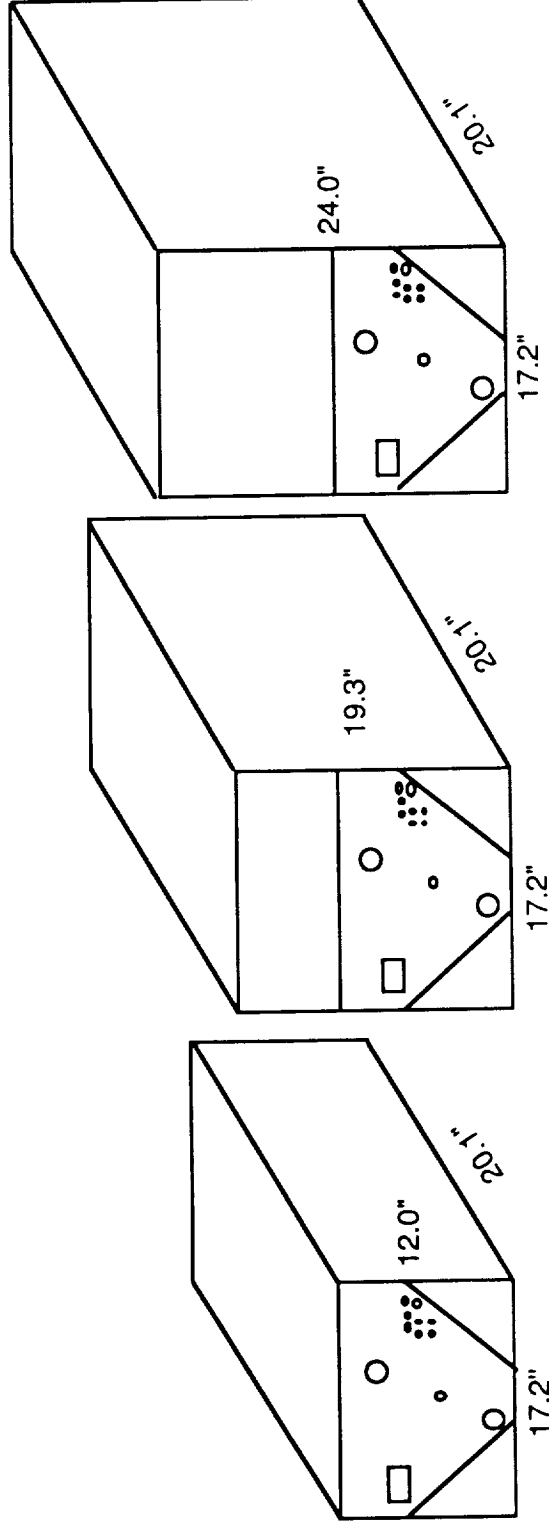
SELECTION OF HABITAT SIZES

- Common width and depth for all habitats
 - Standard 1/2 rack dimension
 - Select 17.2" wide x 20.1" deep
 - Compatible with STS middeck
- Various heights required
 - Select 19" for plants and restrained squirrel monkeys (compatible with STS double middeck accommodations)
 - Select 24" for unrestrained squirrel monkeys
 - Select 12" for rodents (1/2 large size)
- Selected standard interface for all Habitats

BASELINE HABITAT SIZES

The figure on the facing page depicts the selected habitat sizes and location of the standard interface plate of each habitat. The standard interface plate provides connections for power, data, video, RF, experiment water, experiment gases (oxygen, nitrogen, carbon dioxide) and inlet and outlet connections for coolant water and environmental control air. Each habitat has a connector for those utilities that it needs; unused utilities remain unconnected.

BASELINE HABITAT SIZES



- Standard interface plate provides the following connections for habitats
 - Environmental control air inlet and outlet
 - Coolant inlet and outlet
 - Waste liquid outlet
 - Distilled water
 - Gas supply (Oxygen, Nitrogen, Carbon Dioxide)
 - Electrical connections

SPECIMEN CHAMBER SERVICING

Periodic servicing of the specimen chambers is required. This may be accomplished by cleaning and reusing specimen chambers or by disposing and replacing them. The tradeoff between these options involves many variables, as listed on the facing page.

Since WP01 is considering a washer system, a washer was baselined for the system study. However, because there is insufficient information to make a decision between washing and replacing, options will continue to be examined.

SPECIMEN CHAMBER SERVICING

- Washing and/or replacing
- Tradeoff variables
 - Habitat & specimen chamber design
 - Future experiments
 - Freedom resources and logistics constraints
 - Compatibility with specimens
 - Costs and measures of performance
- Equipment washer by WP01
- Baseline washer for study
 - Provide support for WP01 efforts
 - Improve understanding of washer requirements and system interactions
 - Continue investigating replacement option
 - Anticipate decision during or at end of Phase B study
- Insufficient information to make decision at this time

DIVISION OF FUNCTIONS

After the Habitats are installed in the Holding Unit, a variety of functional requirements must be met by the combined Holding System (Holding Unit plus Habitats); some functions are performed by the habitats and others by the Holding Unit. The rationale for division of function between the habitats and the systems is presented on the following pages.

In order to provide flexibility for a broad range of experiments over the life of the program, a standard laboratory approach was adopted toward accommodating users in the Facility. As in a laboratory, large systems such as the Holding Unit, provide standard services to subsystems, such as the habitats, and services unique to a specimen type would be provided by the habitat.

Many of the resources required by the Facility are supplied by Freedom. Therefore, these resources connect directly to the Holding Unit. The Holding Unit distributes Freedom resources necessary for the habitats. These include filtered air or other gases, coolant, water, power, data interface, and purge lines for coolant, air and contaminated liquid. The habitats provide food, nutrients, or other resources unique to the specimens within the habitat. The primary data processing is performed by the Holding Unit to reduce the need for data processing hardware within the habitats.

By providing common resources from the Holding Unit, the habitats are less massive and the Facility volume is reduced by eliminating unnecessary redundancy. Because of volume constraints, the Facility has one exception to this approach; temperature/humidity control is a shared function. This will be discussed in more detail on subsequent pages.

It should be noted that the Centrifuge functions as the Holding Unit so that the discussion above applies equally to the Centrifuge System and Glovebox with minor exceptions.

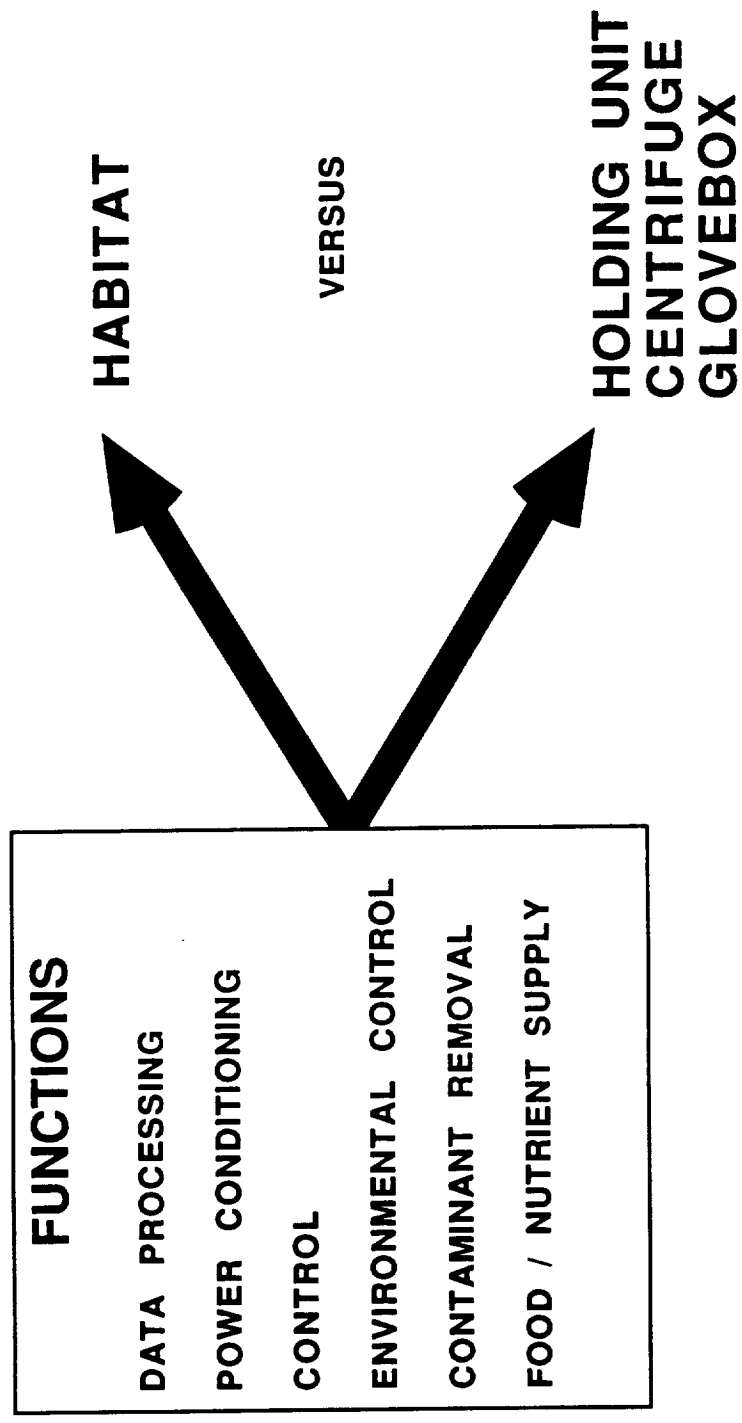
DIVISION OF FUNCTIONS

- System Functions must be logically divided between Habitat and Holding Unit
 - Selected approach must accommodate a broad range of experiments.
- Adopt standard laboratory approach
 - Systems provide general services to habitats including:
power, data interface, gases, filtered air, water, coolant, waste removal
 - Specimen unique services provided by habitat:
food, nutrients, ...
 - Data processing performed by Holding Unit
- System design required that some functions be shared
 - Temperature and humidity control is shared
 - Inlet air cooling and dehumidification by Holding Unit
 - Inlet air heating and humidification by habitats

DIVISION OF FUNCTIONS OPTIONS

The diagram on the facing page illustrates some of the functions to be performed by the Holding System, i.e., habitats and Holding Unit. Rationale on how to partition the various functions between the habitats and systems was discussed on the previous page.

DIVISION OF FUNCTIONS OPTIONS



AIR FLOW

Two options for providing air to the habitats were considered in this study. These were the single pass and recirculating air systems which are illustrated on the following pages.

The single pass system was selected for the baseline to reduce the risks of cross-contamination. In a single pass system, biologically contaminated volumes are downstream of the habitats; the air upstream of all habitats is clean filtered cabin air. Therefore, it is unlikely that cross-contamination will occur between habitats.

AIR FLOW

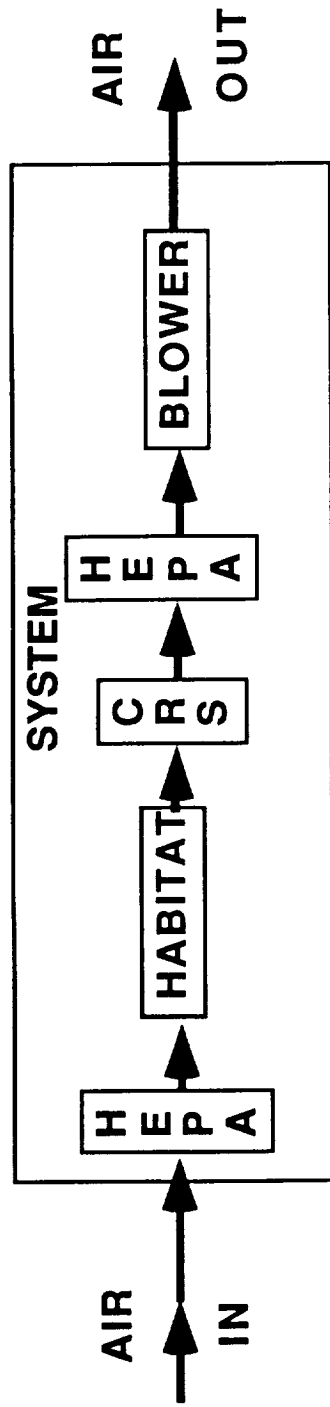
- Airflow: "single pass" vs "recirculating" systems
 - Single pass provides constant stream of fresh air
 - Recirculating recycles through habitats
- Science requirements which impact decision
 - Simultaneous accommodation of mixed specimen types
 - Prevention of cross-contamination
 - Atmospheric composition in specimen chambers
- Selected "single pass" system as baseline
 - Satisfied science requirements
 - Less complex system

AIR FLOW

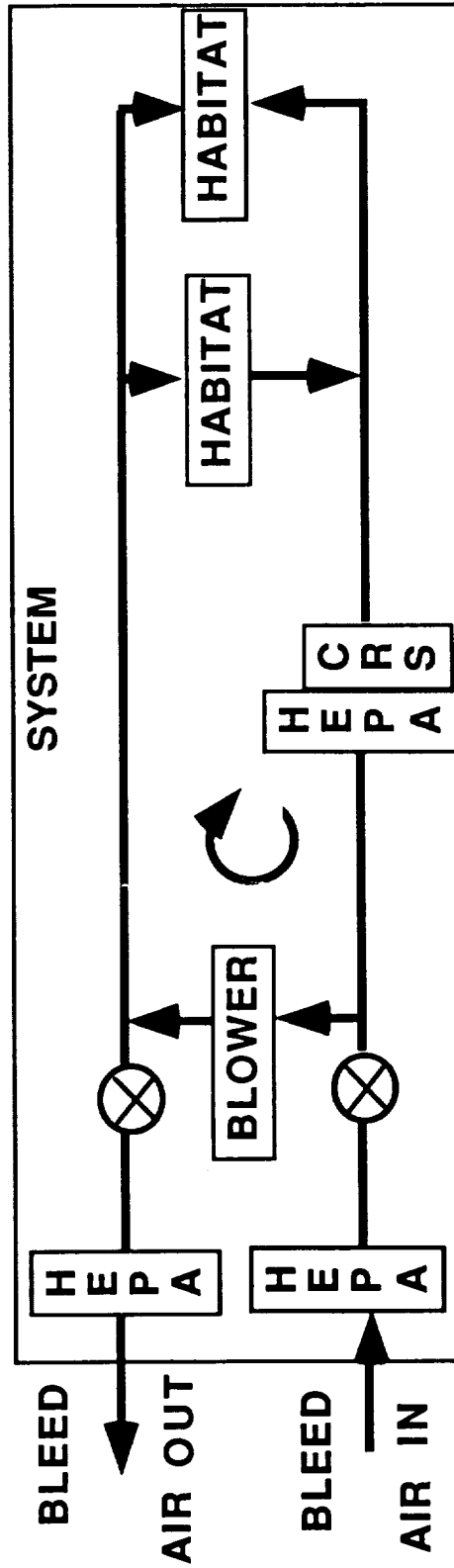
The facing page illustrates functional differences between a single pass and a recirculating air system for habitat environmental control. The diagrams are simplified and intended to be self-explanatory (CRS indicates contaminant removal system).

AIR FLOW OPTIONS

SINGLE PASS SYSTEM (SIMPLIFIED)



RECIRCULATING SYSTEM (SIMPLIFIED)



SYSTEM AIR FLOW RATES

The selection of system air flow rates has cascading design impacts on the Facility. Some of these impacts are described below and summarized on the facing page.

Science requirements specify a wide range of allowable air flows in the habitats. The minimum of 10 volume changes/hr assures that fresh air circulates through the habitats. The maximum of over 1000 volume changes/hr comes from requirements to maintain the velocity of the air below 0.3 - 0.7 m/s, depending on the specimen type. Note that as the Plant Habitats will maintain independent air flows, the following discussion pertains to accommodating animal habitats.

To attain higher air flows, the associated hardware components (blowers, filters, etc.) are relatively large and leave little volume in the parent system for habitats. On the contrary, low flows result in a relative increase in the volume available for habitats. Problems associated with lower air flow include difficulties in uniform flow distribution, inadequate heat removal by respiration air flow, and increases in the response time to maintain environmental control.

As a compromise, biased toward lower air flows to increase volume for habitat accommodations, a total system flow rate of 4700 cc/s (10 cfm) was selected. This would provide between 50-100 air changes/hr for each of the habitats.

SYSTEM AIR FLOW RATES

- Science requirements permit wide range of air flow rates in habitats
- Air flow tradeoffs are complex
 - Air flow controlled at system level outside the habitat
 - Plants use semi-closed air flow system within habitats
 - Variables in tradeoff include power, size of components and ducting, volume available for habitats
- Selected low air flow rate
 - Total system flow of 4700 cc/s (10 cfm)
 - Provides 50-100 air changes/hr for animal habitats

TEMPERATURE AND HUMIDITY CONTROL

Science specifications require tight control of temperatures in the specimen chamber and humidities must be maintained within specified limits. The Freedom cabin, which is used as a source of air to the habitats, operates over a wide temperature and humidity range. The operating envelopes for the habitats and Freedom cabin are shown in a subsequent figure. The rationale for the baseline approach to humidity and temperature control is described below.

To control habitat air temperature and humidity using cabin air at some arbitrary state point requires various combinations of the following hardware: a heat exchanger for cooling, a water separator for dehumidification, a heater, and a humidifier. Two design options were considered to control the habitat air temperature and humidity; one used an independent control loop for each habitat and the other a shared "distributed" control loop with control functions divided between the Holding System and habitats.

Providing individual control to each of the habitats would result in a more efficient operation of the Facility, but would require more hardware. Shared control of inlet conditions to the habitats requires less hardware, but is less efficient and depends on control functions to be carried out by both the Holding Unit and the habitats.

An individual control loop for each habitat could not be implemented without seriously impacting habitat size; for this reason the shared control system was selected for the baseline. These options and a process diagram depicting a possible operating condition within the habitat are shown schematically in subsequent figures.

TEMPERATURE AND HUMIDITY CONTROL

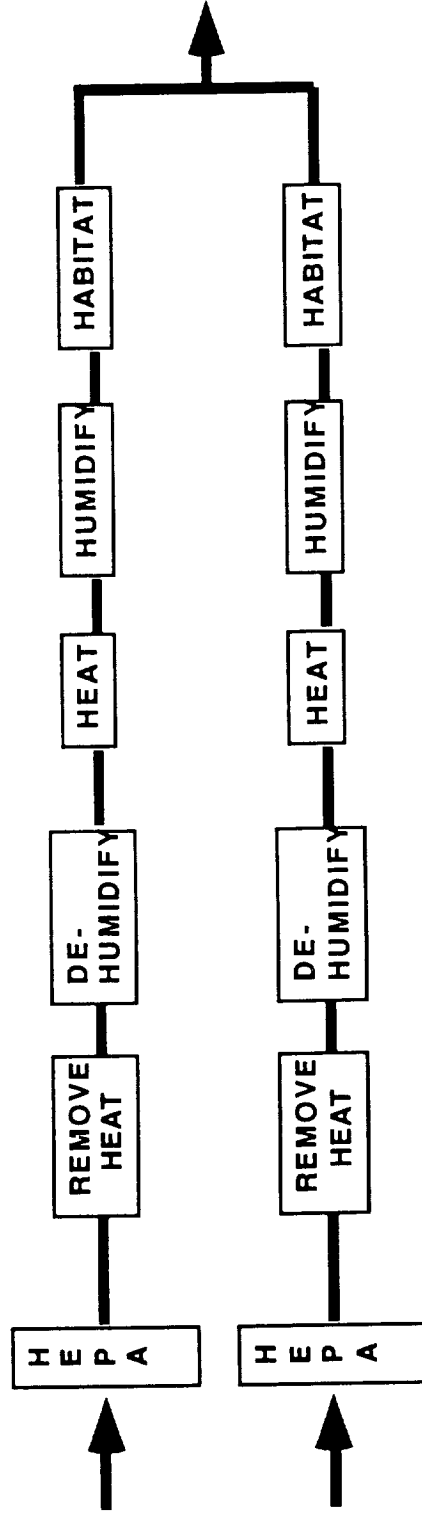
- Science requirements require tight temperature control at habitat
- Temperature and humidity of cabin air not controlled by Facility
- Options considered were "individual" vs "shared" control of the air to each habitat
 - Individual: more efficient; requires more hardware
 - Shared: reduced hardware; requires distributed control functions
- Selected shared control for baseline
 - Increased volume available for habitats
 - Precondition air prior to entering habitat
 - Requires heaters and humidifiers in habitats
 - Will satisfy experiment temperature and humidity control requirements

TEMPERATURE AND HUMIDITY CONTROL (CONT'D)

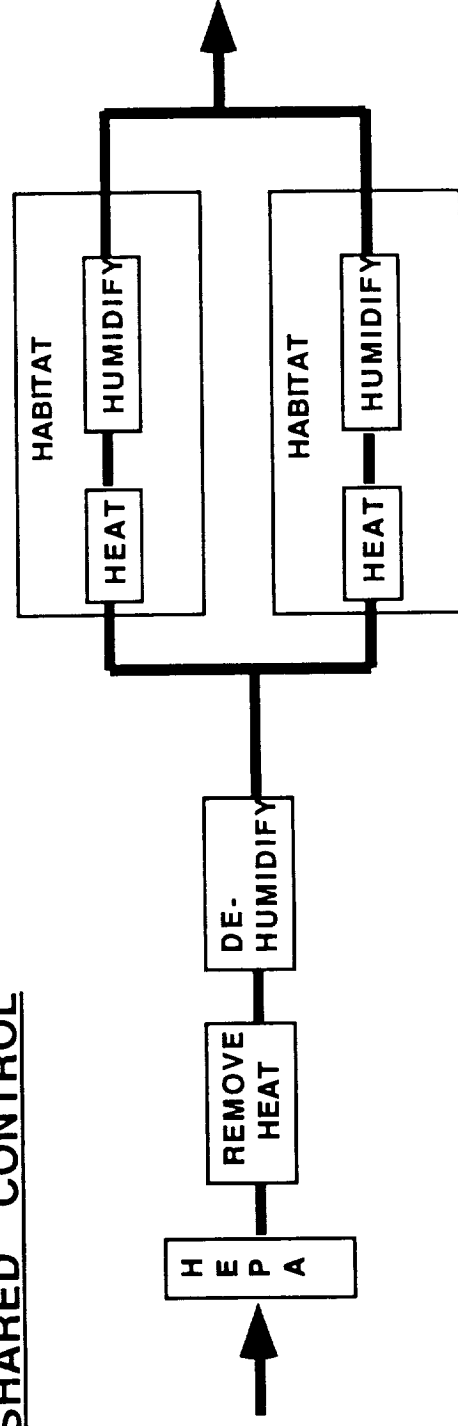
The figure on the facing page is a simplified block diagram which depicts the two temperature and humidity control options examined in this study. The individual control option provides more operational efficiency but because of the additional hardware required, it reduces the volume available for habitats within the racks. The shared control system was selected for the baseline.

TEMPERATURE AND HUMIDITY CONTROL (CONT'D)

INDEPENDENT CONTROL



SHARED CONTROL

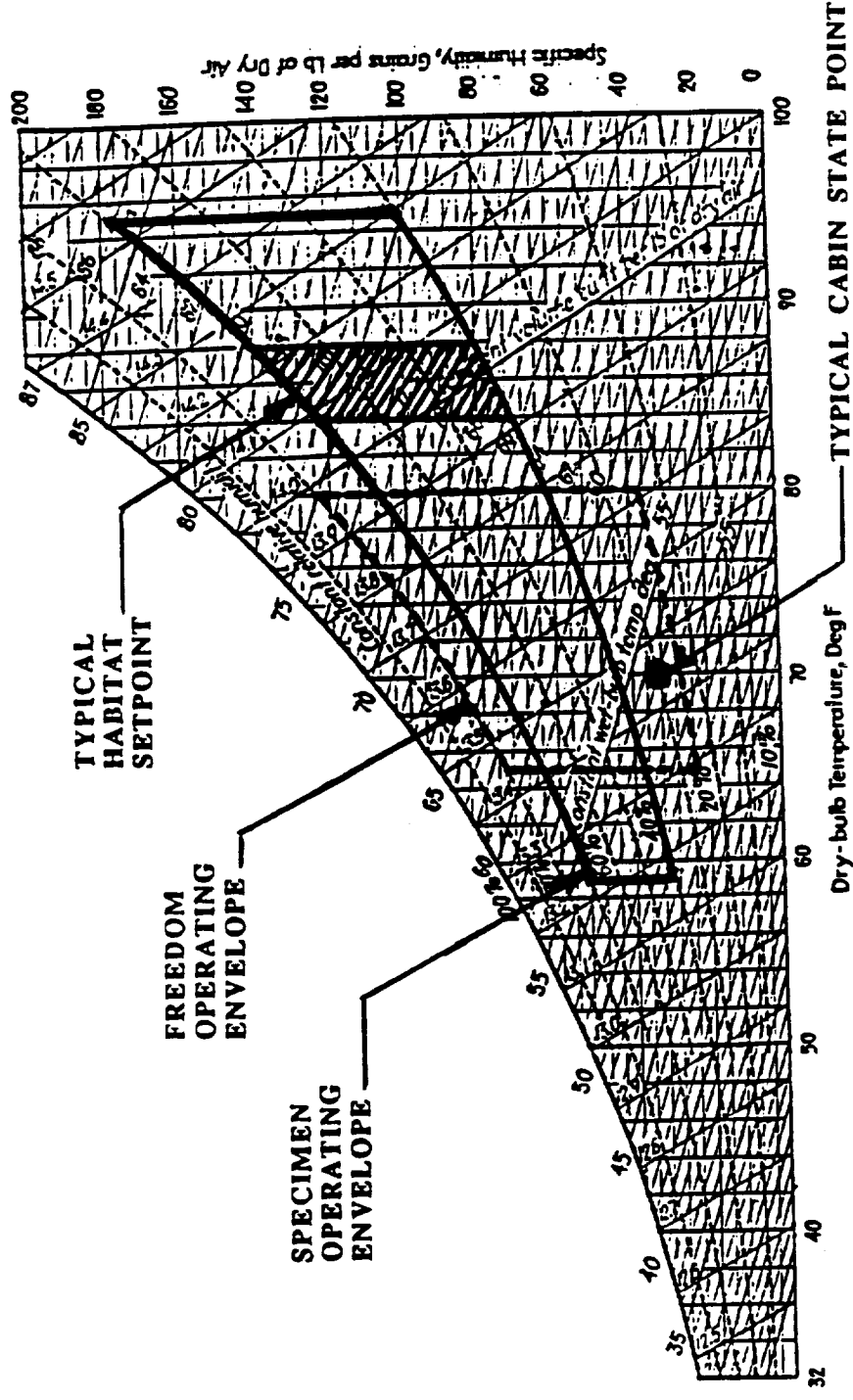


TEMPERATURE AND HUMIDITY OPERATING POINTS

The figure on the facing page shows the operating envelope of temperature and humidity for specimens as defined by the science specifications (solid line) and the Freedom cabin air operating envelope (dashed line) superimposed on a standard psychrometric chart.

A typical habitat setpoint is shown by the crosshatched region in the specimen operating envelope. This crosshatched region could be at any arbitrary location within the specimen operating envelope, depending on the requirements specified for a particular experiment. Similarly, the cabin state point could be at any location within its operating envelope. To move from any arbitrary cabin state point to any arbitrary specimen operating condition in general requires various combinations of the following functions: cooling, dehumidification, heating, and humidification. A process diagram illustrating a combination of these is included in the appendix.

TEMPERATURE AND HUMIDITY OPERATING POINTS



- To move from Freedom state point to habitat operating condition requires:
 - Cooling
 - Dehumidification
 - Heating
 - Humidification
 - Combinations of the above

ON-ORBIT TRANSPORT OF HABITATS

Science specifications require that specimen environments remain relatively unperturbed except when experiment manipulations are intended in the Glovebox. The purpose of this requirement is to minimize perturbations to the experiment which may affect experimental results.

To provide environmental control and power during the times when habitats are moved from one location to another, a separate transporter module which plugs into the habitat interface plate at the rear of the habitat was selected for the baseline design. This transporter module would be used when the detached habitat could not be immediately inserted in the receiving system.

A preliminary assessment indicated that it would be difficult to maintain complete habitat environmental control (maintain air temperatures and humidity) within a small transporter module. The design of the transport module was not addressed in this study and will be addressed in the future.

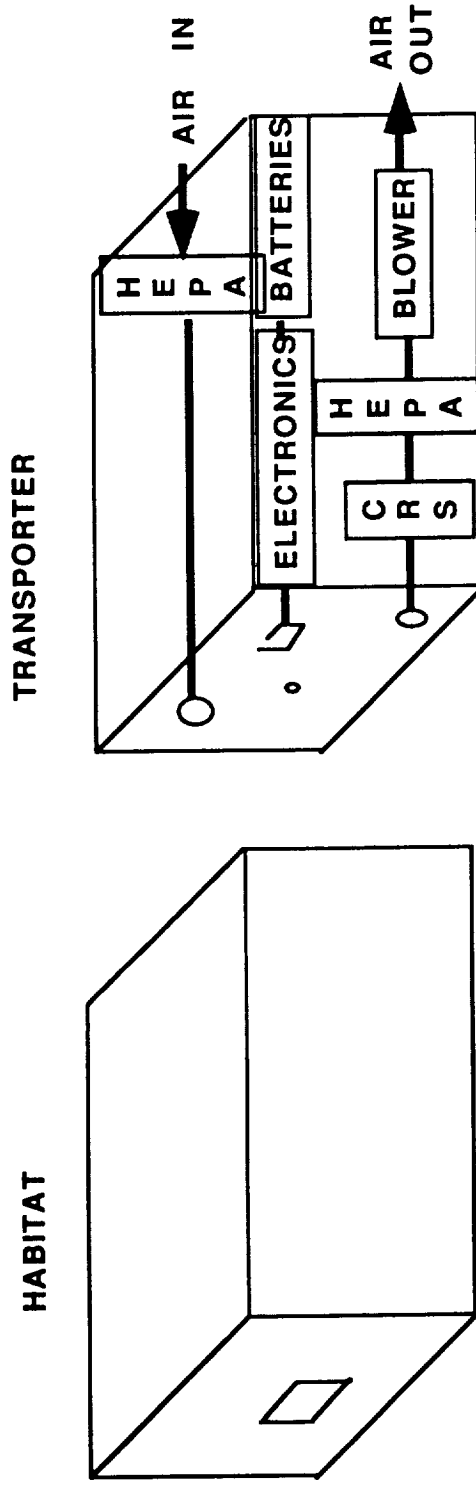
ON-ORBIT TRANSPORT OF HABITATS

- Specifications require relatively undisturbed specimen environments during on-orbit transport between stations
 - Same temperatures as during operation within slightly larger tolerances
- Baseline designs assume separate "Transporter"
 - Transporter attaches to rear of habitat after extraction
 - Provides power and environmental control functions
- Design of Transporter not addressed in System Study

ON-ORBIT TRANSPORTER

The schematic on the facing page illustrates the on-orbit transport module envisioned for use with the baseline modular habitats. It provides power to the habitats from rechargeable batteries, has an electronic control system, and provides a continuous air circulation through the habitats. For the concept shown, cabin air is circulated directly through the habitats; no temperature or humidity control is provided. The transporter plugs into the back of the modular habitats.

ON-ORBIT TRANSPORTER



CONCLUSIONS

The study indicated that a Centrifuge Facility (based on the use of standard Freedom racks) could be developed that would satisfy most science requirements. The major science requirements not satisfied were the incorporation of an automatic habitat extractor on the Centrifuge and the ability of the Centrifuge to support Unrestrained Squirrel Monkey Habitats. It is anticipated that these requirements can be met by a larger Centrifuge located in a node. Subsequent studies will examine this possibility in depth. Packaging will be a major design challenge that will require in-depth engineering and perhaps some relaxation of requirements in order to accommodate the desired number of specimens in each system.

CONCLUSIONS

- A Facility can be developed to support the Science Requirements
- Significant design challenges identified
 - Centrifuge habitat extractor and accommodation of unrestrained primates in the Centrifuge are only major requirements not met ; problems should be eliminated by Node location
 - Other problems can be overcome by combination of in-depth engineering & modest relaxation of requirements

APPENDIX

The remaining pages of this chapter describe, in more detail, the process of temperature and humidity control.

APPENDIX

Temperature and Humidity control

Process Diagram

Thermodynamic Process

TEMPERATURE AND HUMIDITY CONTROL

One of the features which distinguish the Centrifuge Facility from previous space biological research efforts is the requirement to control the environment (i.e., temperature and relative humidity) much more accurately. However, random water addition (e.g., urine, water from lixits) and its evaporation may make it difficult to achieve the relative humidity and temperature set-point accuracy. A number of design challenges to meeting environmental control are listed on the facing page.

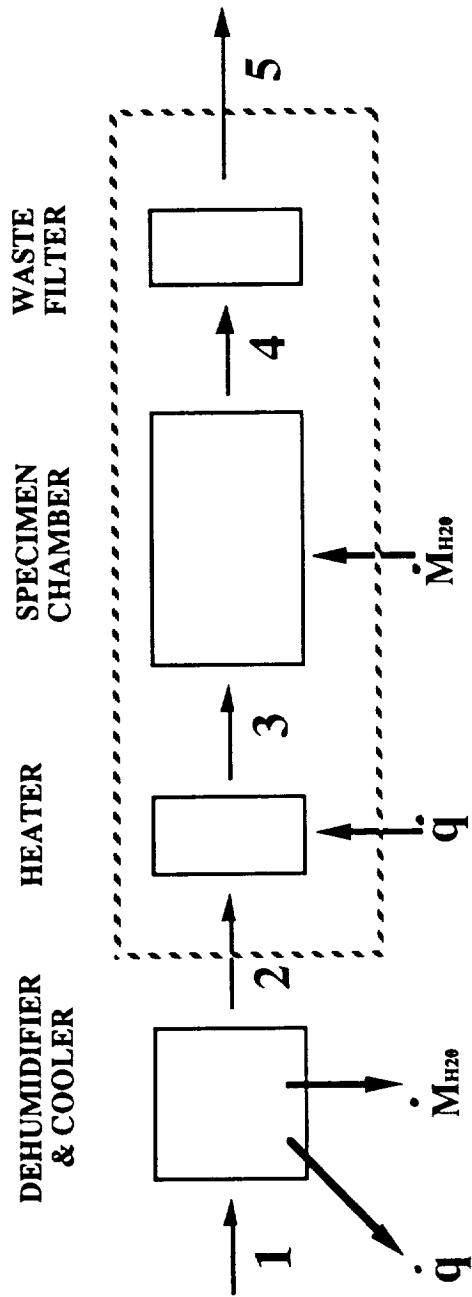
TEMPERATURE AND HUMIDITY CONTROL

- Temperature/Humidity Control
 - Baseline animal habitat uses a heater and water humidifier
 - Temperature will be affected by thermodynamic processes within specimen chamber, making it difficult to maintain temperature to ± 1 degree C.
 - Relative humidity (RH) will be difficult to maintain within $\pm 15\%$ due to random water additions from animals
 - Habitats on Centrifuge may behave differently than 0-g Habitats
 - Control system should aim at long term averages

PROCESS DIAGRAM

To illustrate some of the difficulties associated with accurate control of the thermodynamic parameters (e.g., temperature and humidity), a process diagram accompanied by a psychrometric chart is shown on a subsequent page. Point 1 on the facing page is an arbitrary thermodynamic set point for the Space Station cabin air. This is the initial condition for the Holding System, Glovebox and Centrifuge System environmental control system. The control problem is as follows: Given a variable Space Station cabin air set point, control the habitat environment to within the desired constraints while allowing each habitat to be individually controlled.

PROCESS DIAGRAM



| PROCESS: | |
|----------|------------------------------|
| 1 | → DEHUMIDIFICATION & COOLING |
| 2 | → HEATING |
| 3 | → WATER ADDITION |
| 4 | → ADIABATIC SATURATION |

| | |
|------------------|------------------|
| \dot{q} | - Heating rate |
| \dot{M}_{H_2O} | - Mass Flow Rate |

THERMODYNAMIC PROCESS

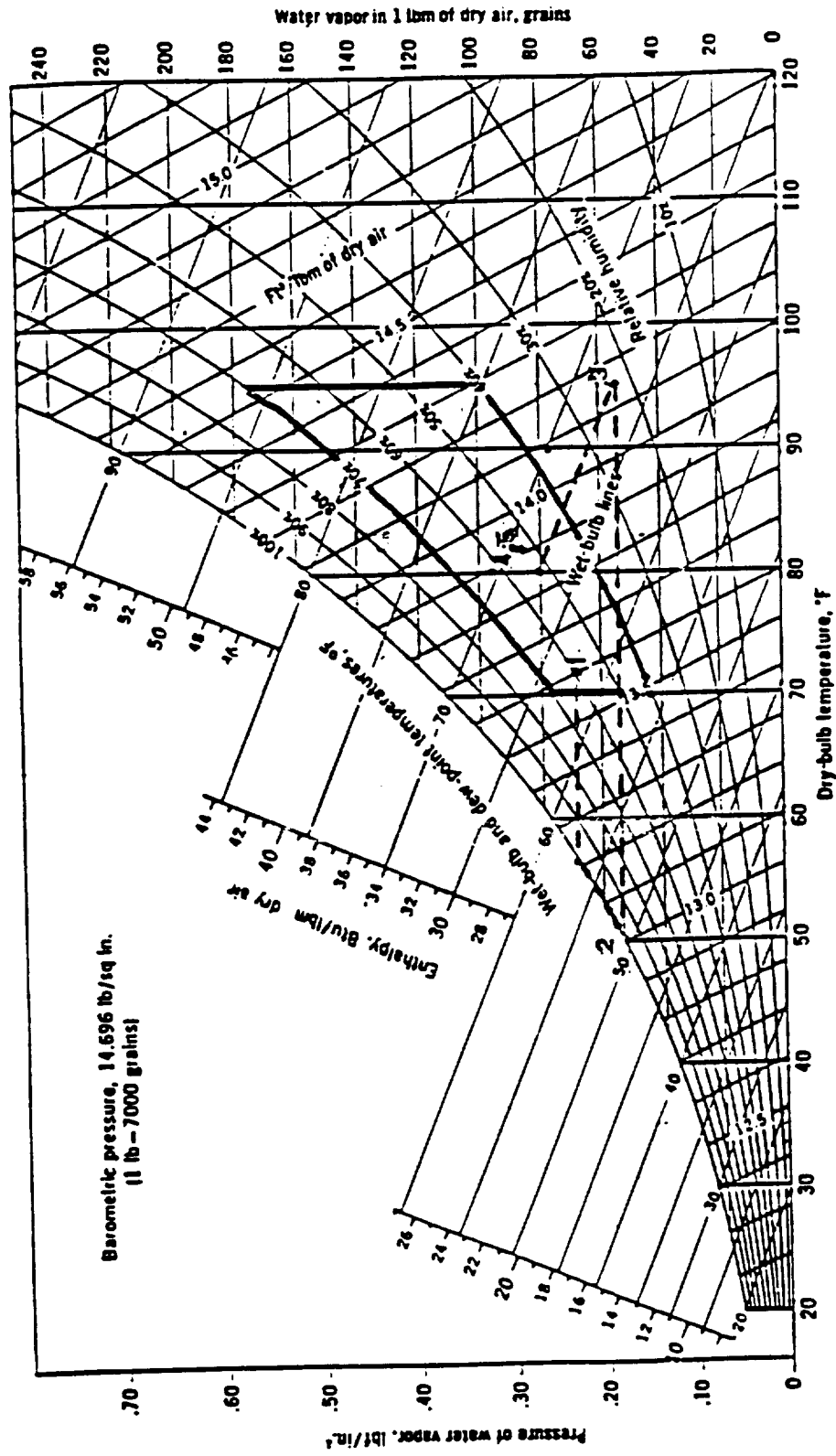
Refer to the process diagram on the previous page and the psychrometric chart on the facing page for the discussion below.

From state 1, if all of the habitats in the Holding System can be conditioned with just an addition of heat, then only the strip heaters inside the habitat need be used. In the more likely case that the relative humidity must also be conditioned, the Facility must be designed to respond in the following manner.

From state 1 to 2, the air stream undergoes either cooling or dehumidification. This depends on the location of the initial state point 1 and the desired thermodynamic target points for the habitats. The psychrometric chart displays the cooling and dehumidification process to state point 2. From state point 2 to state point 3, the air stream is heated to the desired temperature inside the habitat. In this particular case, the relative humidity is too low and water must be added in order to attain the desired relative humidity. Urination by the specimen, especially if in the upstream direction, also affects specimen chamber humidity. This will considerably affect humidity depending on the number of rodents within the specimen chamber and whether or not the habitat is in the Centrifuge or Holding System. In general, the Centrifuge centrifugally accelerates the habitats which will propel the urine more quickly into the waste tray and thus the habitat will generally be less humid on the Centrifuge.

Returning to the psychrometric chart, the adiabatic cooling process which follows the lines of constant enthalpy along 3-4-5, is highly dependent on the above circumstances. State 4-5 characterizes the humidification process across the moist waste tray in which water is taken up in the stream. State point 4, the state point of the specimen chamber, may not be well known and at times may be difficult to control. If a particular habitat is too dry due to either a dry cabin or experimental circumstances, water may have to be added to the specimen chamber in order to raise the long term average relative humidity in that habitat. Because the temperature and relative humidity are interdependent, it is difficult to have a control system that responds to short term water injections (i.e., from specimen urination). Therefore, the control system will only control the average humidity over an extended time interval.

THERMODYNAMIC PROCESS



CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 2

Rodent Habitat

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INTRODUCTION

The preliminary design concept for a modular rodent habitat was driven by the following key points:

- a) The Rodent Habitat design is presented as an evolution of previous flight hardware for rodent research. Whenever possible, the subsystems from other flight hardware were considered in forms appropriate for the current system concept. In other words, it was not the intention to altogether reinvent the Rodent Habitat but to borrow as much as appropriate from previous designs.
- b) The design was kept mechanically simple. The modular habitats will be moved frequently within the Facility therefore the design must be rugged. As an example, a simple waste collection system was favored over systems requiring moving mechanical parts to reduce the risk of operational failure.
- c) Some of the common habitat control functions were moved to the Holding System level. This was done to reduce the mass and the complexity of the habitat.
- d) The design goal was to accommodate as many rodents as possible within a habitat by incorporating a specimen chamber with a large unobstructed volume.

The facing page presents the outline for this chapter of the report.

OUTLINE

- Primary Requirements
- Rodent Habitat Description
- Block Diagrams
- Habitat Configuration
- Habitat Characteristics
- Habitat Interfaces
- Habitat System Tradeoffs
- Operational Scenarios
- Design Challenges
- Requirements not Met
- Technology Development
- Summary
- Appendix - Alternate Concepts

PRIMARY REQUIREMENTS

The rodent science requirements both drive and constrain the overall design of the modular habitats. The following chart briefly lists these requirements as well as the extent to which each requirement was or was not met (the facing letters provide that determination: M indicates met; P indicates partially met; N indicates not met; U indicates unknown).

PRIMARY REQUIREMENTS

| | |
|---|---------|
| • Water: Accessible at all times; | Status: |
| At least 2 licks for > 2 specimens | M |
| • Illumination: 5-100 lux, adjustable photoperiod | P |
| • Temperature: Controlled 18-30° C ±1 °C | P |
| • Humidity: 40-70% RH | P |
| • Air composition: Cabin air with contaminant removal | M |
| • Waste collection: Positive capture system | M |
| • Specimen size: Up to 600 grams | M |
| • Chamber Size: 15.2cm (6") high, 20.3cm (8") stretch dimension | M |
| 271cm ² (42 in ²) per rat or 1084cm ² (168 in ²) per 6 rats | |

M=met P=partially met N=not met U=unknown

PRIMARY REQUIREMENTS (CONT'D)

To satisfy specific experiment requirements, the specimen chamber must be reconfigurable to accommodate group housing (up to 6 rats) or individually-housed rodents. Neither vibrational nor acoustical isolation were addressed in this study. However, studies concerning this issue will be performed and appropriate action taken, if needed, as the design matures. For the animal's health and well-being, a waste management system is required to capture the animal's waste products (food crumbs, hair, dander, urine, and fecal matter) and to prevent the animals from gaining access to these waste products. The habitats will require periodic servicing. To meet science requirements, the design must be able to accommodate periods between servicing of at least 14 days. The airflow constraints permit a wide range of permissible operating conditions.

PRIMARY REQUIREMENTS (CONT'D)

| | |
|---|---|
| • Configuration: Reconfigurable specimen chamber; tactile retreats, 20.3cm (8") stretch dim. | M |
| • Vibration/ Acoustics: Not to exceed 73 dB 20Hz-40kHz | U |
| • Cleanliness: Periodic servicing | M |
| • Specimen Monitoring: Critical items monitored | M |
| • Number accommodated: ≤6 rats , reconfigurable | P |
| • Airflow: ≥10 changes/hour, ≤ 0.3 m/s (60 ft/min) constant flow, ≤ 1.2 m/s (240 ft/min) pulsed flow | M |

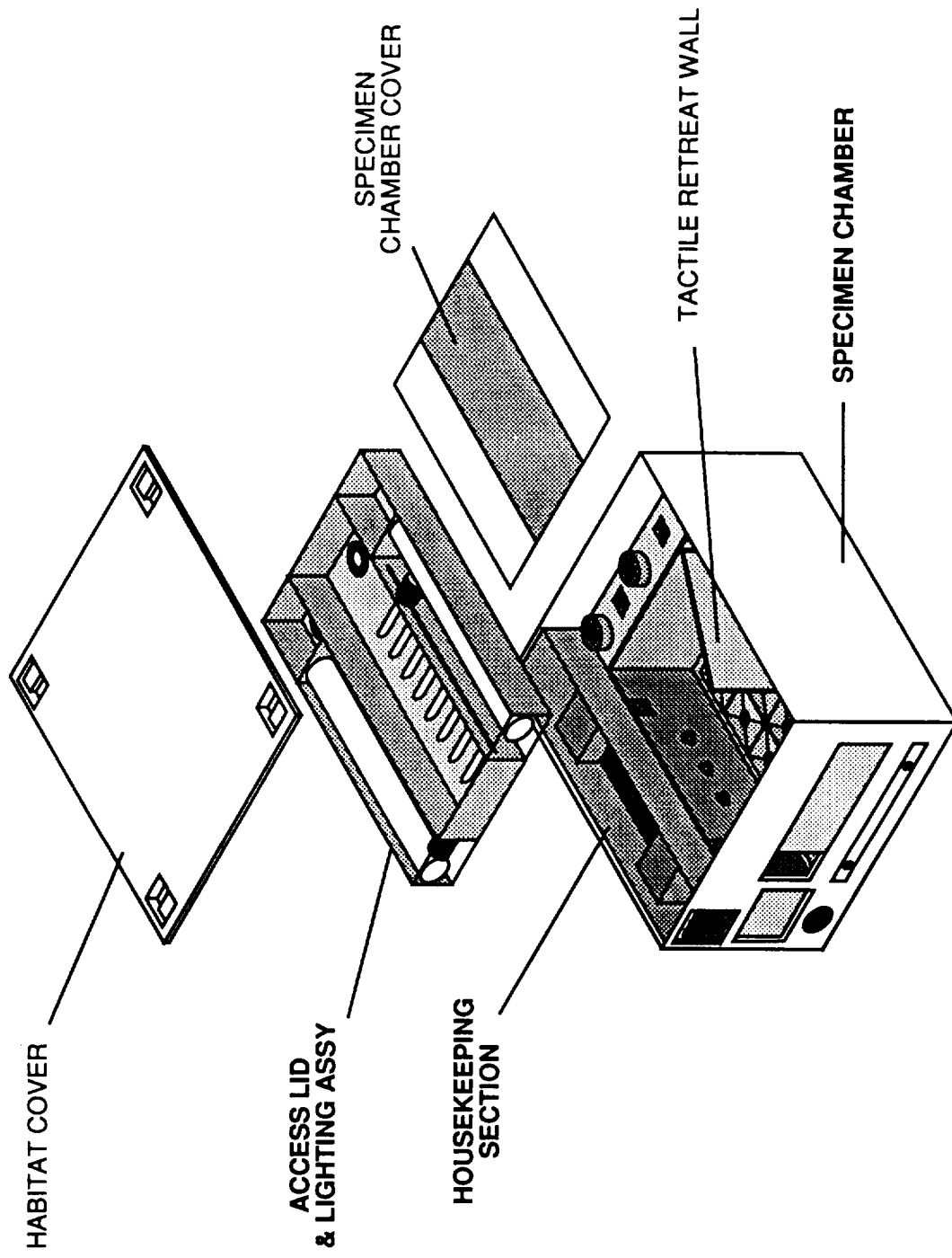
M=met P=partially met N=not met U=unknown

HABITAT DESCRIPTION

An isometric view of the Rodent Habitat concept is provided on the facing page. The three major sections and accompanying subsystems are described in subsequent pages. The tactile retreat wall is oriented parallel to the flow, to prevent waste from accumulating on the wall. The specimen chamber cover is positioned between the access lid and the specimen chamber.

Alternate habitat concepts are presented at the end of this chapter.

HABITAT DESCRIPTION



HABITAT DESCRIPTION (CONT'D)

The habitat is illustrated in a subsequent figure and described below. The Rodent Habitat external dimensions are 43cm wide x 51cm deep x 30cm high (17" x 20" x 12"). Of existing space hardware for rodent research, the Rodent Habitat most resembles the Animal Enclosure Module (AEM) in terms of the principal system features and external dimensions. The habitat is subdivided into three major sections: a specimen chamber, a housekeeping section and an access lid. These major sections are in turn subdivided into various subsystems.

The specimen chamber is the section in which the rodent specimens are housed. Mechanical simplicity was sought in the design of the specimen chamber since this is the habitat element that will require the most servicing. As an example of this simplification, there was an attempt to reduce the number of connections from the habitat to the specimen chamber. Four tube-like structures from the habitat housekeeping section deliver food and water across the specimen chamber wall. These tube-like structures are common to one wall thus simplifying connection and sealing of the specimen chamber wall to the habitat.

The bottom of the specimen chamber is connected to a detachable waste tray which is described in more detail in a later section. To remove the waste tray in the Glovebox, the entire specimen chamber is first removed and the waste tray is subsequently removed. The intent was to provide a means of preventing waste material from contaminating either the specimen chamber receptacle in the habitat or the lid section.

HABITAT DESCRIPTION (CONT'D)

- General Configuration
 - External shell size is 43cm x 51cm x 30cm (17" x 20" x 12")
 - 3 major sections: Specimen Chamber, Housekeeping and Access Lid

C-2

HABITAT DESCRIPTION (CONT'D)

The specimen chamber can be reconfigured by adding walls or other structures for specific experiment requirements. These walls would be coated with hydrophobic materials and aligned parallel to the air stream in order to reduce waste accumulation on the walls. As shown in a subsequent figure, the walls partition the specimen chamber into sectors to individually house rodents. Depending on the partition configuration, the standard water and food dispensers will not reach all of the rodent sections. Another means of food and water delivery would be required (e.g., food bars and AEM style water dispensers) for these configurations.

The housekeeping section is 'L' shaped and contains most of the complex habitat electronics and mechanisms. A top view which follows shows the layout of the equipment. The rear section contains the common interface plate which provides the female quick disconnect elements for respiration air, water, electronic and power connections. The side section contains food cassettes, water and electronics. This configuration allows the food cassettes to be withdrawn through a side access door without violating bioisolation.

The access lid fits on top of the specimen chamber and contains two video cameras, the inlet respiration plenum, the respiration air heating element, and electrical connections from the specimen chamber. The sensors and other electrical elements for the specimen chamber are mounted on removable walls inside the specimen chamber and attach directly to the access lid. In this fashion, the specimen chamber walls do not have electrical attachments, thus simplifying the chamber walls. The access lid connects to a lip in the habitat housekeeping zone and is the primary interface between the specimen chamber and the habitat housekeeping zone.

HABITAT DESCRIPTION (CONT'D)

- **Specimen Chamber**
 - Easy maintenance and cleaning
 - Total volume 26,700 cm³ (1632 in³); Floor space 1,300 cm² (204 in²)
 - Allows group and individually housed rats
- **Housekeeping Section**
 - Electronics
 - Food and water accessible from side of habitat
- **Access Lid**
 - Provides light
 - Two BW/Color video cameras on slide
 - Inlet respiratory air plenum
 - Electrical connections to Specimen Chamber

HABITAT DESCRIPTION (CONT'D)

The baseline food dispenser design provides a 14 day supply of food for 4 rats (14 days is the desired service interval). It would have been possible to scale up the size of the pellet cassette to provide 14 days of food to 6 rats, but the consequent reduction in the specimen chamber internal volume was considered to be excessive; the food delivery subsystem would have increased in size by 50%. A compromise was considered appropriate to maintain adequate specimen chamber volume for 4 rats and the desired 14 days service interval.

The water subsystem provides water *ad libitum* to the rodents. An internal reservoir contains 1 day supply and is connected to two licks which protrude into the specimen chamber. The water metering system is based on Rodent Animal Holding Facility (RAHF) technology but will require some development to reduce the mass and volume.

There are two air loops in the habitat; one for respiration air and the other for electronic cooling air. Due to the bioisolation requirement, both are kept entirely separate. From thermodynamic considerations at the system level, it was prudent to select a low air flow rate (approximately 470 cc/s (1 CFM)). The low air flow rate requires far less energy than a higher air flow to condition the air to the desired temperature and humidity range. From inlet conditions defined at the rack level, the temperature in the habitat is set by controlling the strip heater located in the habitat inlet plenum (in the access lid). Under certain conditions, it may be necessary to inject water into the habitat in order to control the specimen chamber humidity. This is accomplished by the inclusion of a water injection mechanism which will increase the long term average humidity level in the specimen chamber. This level of environmental control is a considerable departure from previous rodent space flight hardware in the extent to which the environment is controlled (i.e., temperature and relative humidity).

HABITAT DESCRIPTION (CONT'D)

- Food
 - Pellet dispenser provides 4 rats 14 days food supply
 - Pellet cassettes replaceable through Housekeeping section access door without requiring Glovebox
- Water
 - Provides potable water ad libitum via two lixits
 - Internal 1 day supply with RAHF style metering units
- Air
 - Holding System provides fixed inlet temperature
 - Air is heated in the inlet plenum with strip heaters for desired temperature
 - Water is injected to achieve the desired humidity range
 - Single pass system with low airflow: $470\text{cm}^3/\text{s}$ (1 CFM or 60 changes/hour)

HABITAT DESCRIPTION (CONT'D)

The lighting system must illuminate the specimen chamber in a range of 5-100 lux with an adjustable intensity and photoperiod. Supplying light in this range is not a problem. However, adjustments of intensity may only be reasonably achieved with an incandescent bulb of the type flown with previous rodent space flight hardware. There is a penalty associated with incandescent bulbs due to a relatively low efficiency which requires a larger heat removal system than other types of lighting. For this reason, fluorescent lighting is chosen over incandescent lighting. The ability to control lighting intensities will be limited.

Waste management is a key element of the Rodent Habitat. However, designs that required electro-mechanical devices were rejected to maintain simplicity as a design objective.

The waste management system relies on air flow in conjunction with hydrophobic materials to gradually blow the waste into the waste tray. A modified RAHF waste tray was chosen as the simplest approach to waste containment.

The thermal management system relies on a separate air flow system of 4,700 cc/s (10 CFM) to cool the lights and electronics. In an earlier design with higher airflow rates, the respiration air flow was used to cool the electronics. However, at 470 cc/s (1 CFM), this airflow rate is inadequate to remove the produced heat. A separate system with a higher air flow was used to reject heat to the cabin air.*

* Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore this feature of the design will have to be modified.

HABITAT DESCRIPTION (CONT'D)

- **Lighting**
 - Two fluorescent bulbs provide 5-100 Lux, adjustable period
 - Air cooled via cabin air
- **Waste Management**
 - Waste tray is attached to bottom of specimen chamber
 - RAHF style tray concept using air with absorptive materials
- **Thermal Management**
 - Light and electronic heat load removed with small fan in separate air loop and rejected to cabin air

HABITAT DESCRIPTION (CONT'D)

Environmental monitoring is accomplished through the use of sensors mounted to the tactile retreat and separation wall structure. As indicated previously, this resulted in a simplification of the specimen chamber. An activity monitor, independent of the video cameras, would be similarly placed.

The tactile retreat is constructed of movable wall panels aligned parallel to the air flow and attached to either the waste tray cover, the specimen chamber walls, or the specimen chamber cover. A hydrophobic coating helps prevent urine and fecal material from adhering to the side of the walls. The geometry of the tactile retreat would vary with the number of specimens and experiment objectives.

Bioisolation is one of the major habitat design requirements. Many aspects of the design of the habitats are concomitant to bioisolation. The bioisolation requirements are:

- 1) Prevent cross-contamination between specimens and different experiments
- 2) Maintain at least two levels of bioisolation between the Space Station and the individual experiments.

The Rodent Habitat achieves two levels of bioisolation using:

- 1) HEPA quality filters at the respiration air inlet and exit
- 2) An air flow system that operates under negative pressure relative to the cabin during normal operation.
- 3) Two layers of physical containment provided by habitat structure and specimen chamber.

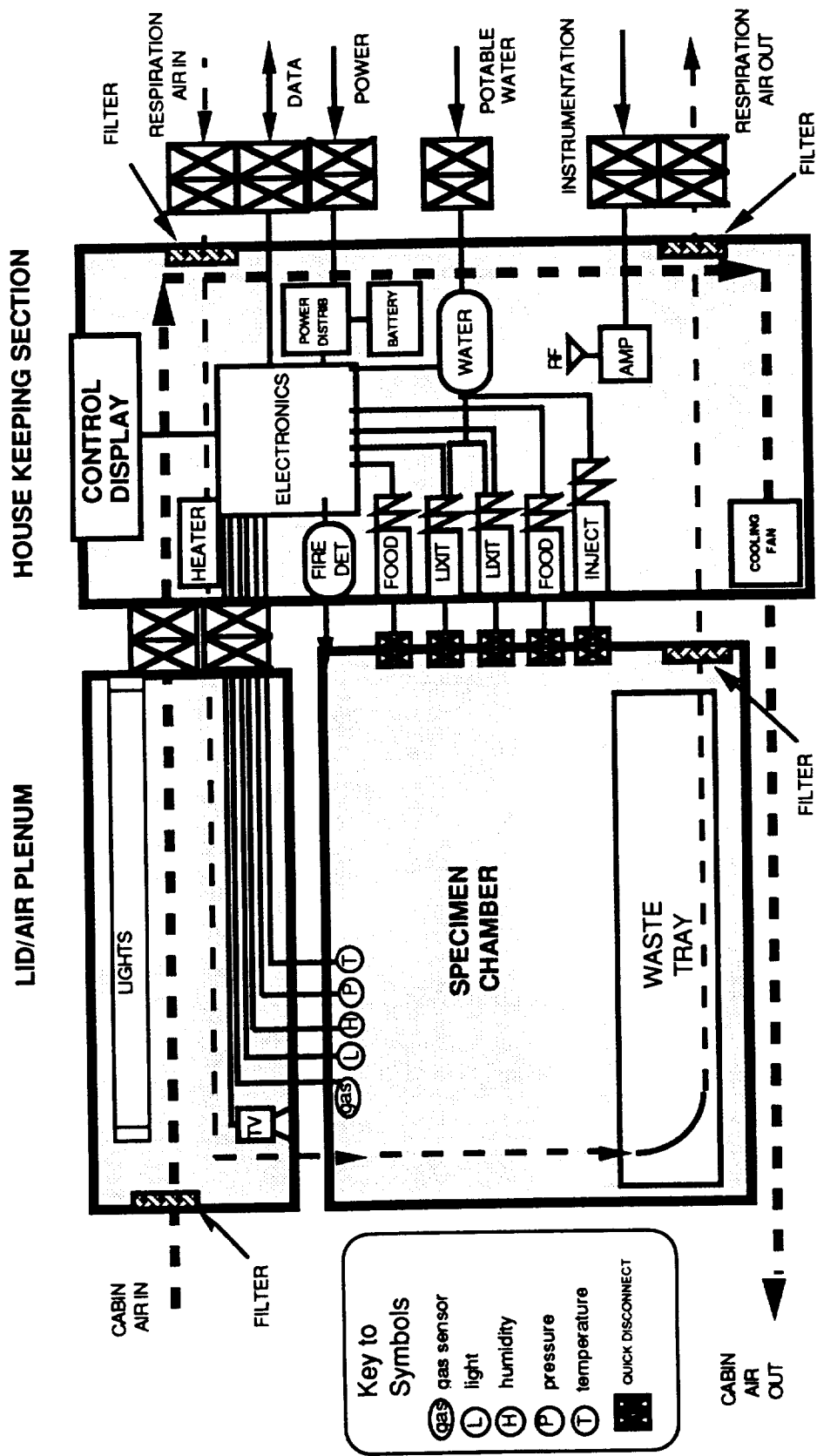
HABITAT DESCRIPTION (CONT'D)

- **Environmental Metering and Activity Monitor**
 - Sensors (CO₂, T, RH) mounted in tactile retreat structure
 - Video provided (BW and color)
- **Tactile Retreat**
 - Tactile retreat provided parallel to air stream to avoid dead air spaces
 - Accommodates 1-4 rats
- **Bioisolation**
 - HEPA quality filters provided at inlet and exit

LIFE SUPPORT BLOCK DIAGRAM

The Rodent Habitat life support block diagram is depicted on the following page. The flow paths of the two separate air loops through the three major sections, the housekeeping, lid/air plenum, and specimen chamber are shown; respiration air inlets and outlets are to the right and cabin air inlets and outlets are to the left. The two filters at the respiration air inlet and exit are of HEPA quality and provide one level of bioisolation. Note the simplicity of the specimen chamber relative to the complexity of the lid/air plenum and housekeeping section.

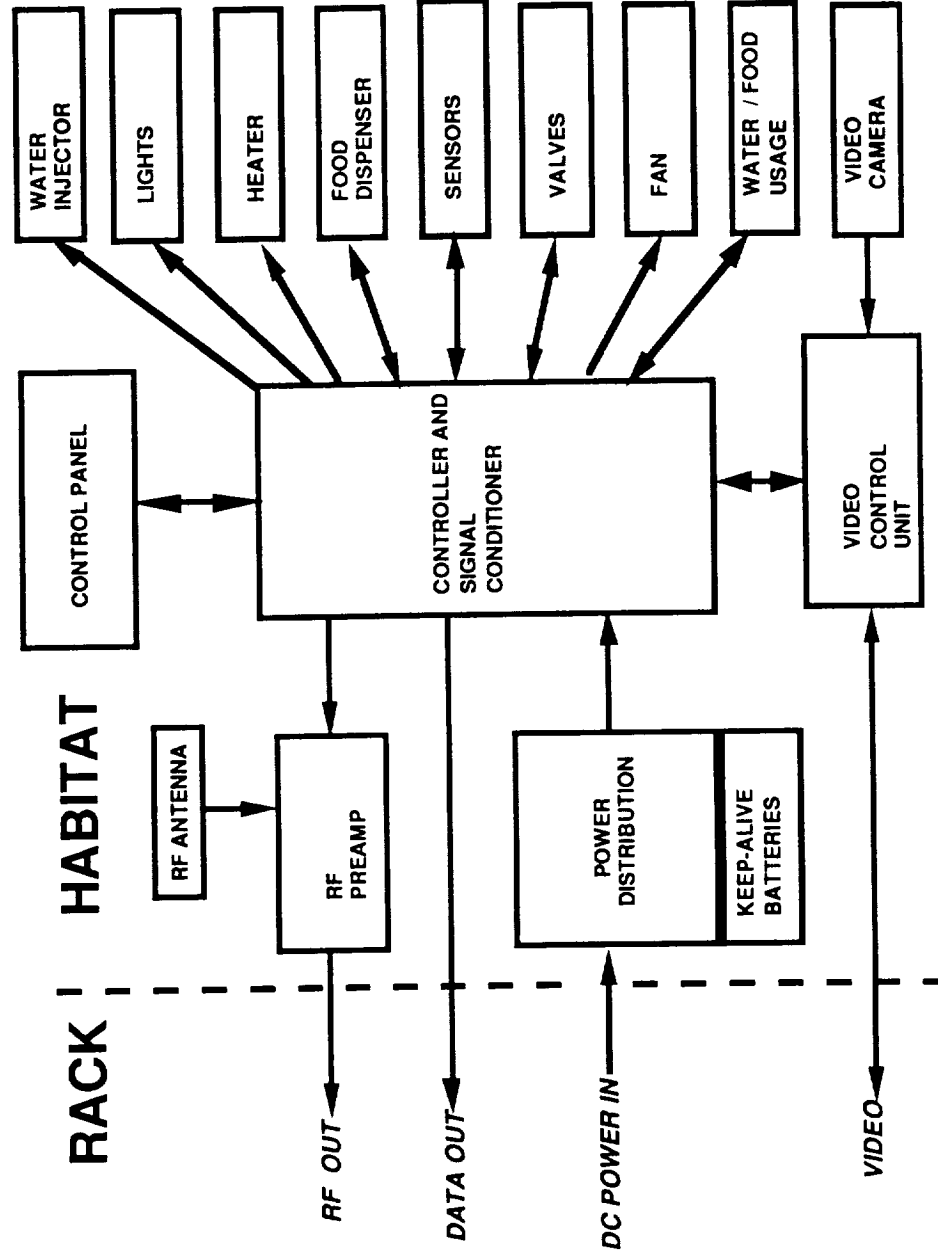
LIFE SUPPORT BLOCK DIAGRAM



ELECTRONIC BLOCK DIAGRAM

The electronic block diagram is shown on the facing page. The main controller and signal conditioner in the center of the diagram controls the various habitat electronic subsystems seen on the right hand side. For animals which have implanted sensors, an RF antenna in the housekeeping section of the habitat receives the signal. The signal is then boosted in the pre-amp and sent to the Holding Unit.

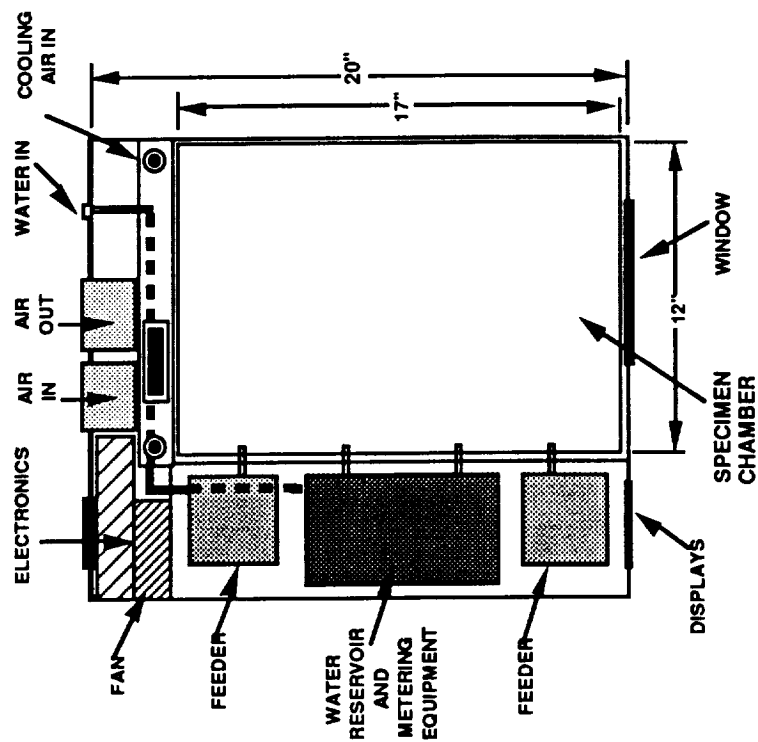
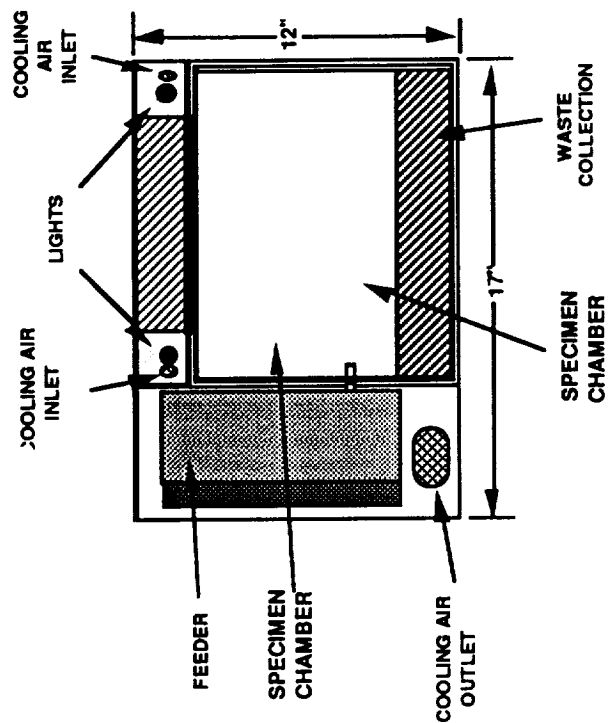
ELECTRONIC BLOCK DIAGRAM



HABITAT CONFIGURATION

A front and top view of the Rodent Habitat is shown on the facing page. The placement of the major habitat subsystems is evident. The cooling air flows under the feeder and water subsystem and exits at the front of the habitat.

HABITAT CONFIGURATION



HABITAT CONFIGURATION (CONT'D)

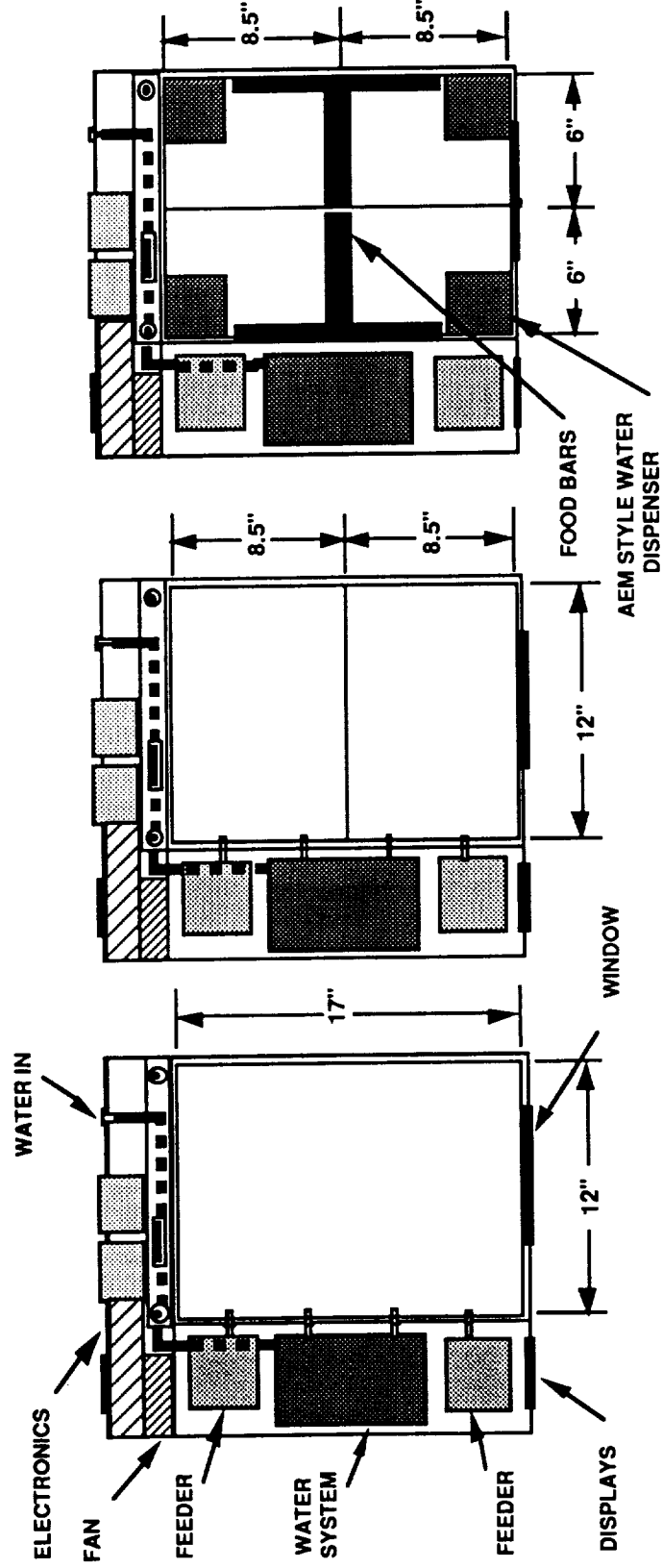
The specimen chamber may be reconfigured by inserting movable walls as shown on the facing page. The first figure on the left shows the group housed configuration in which no separation walls are inserted. The center figure shows how the habitat may be partitioned into two separate chambers by inserting a central wall. In this configuration, two rats have individual access to the food and water subsystems. The figure on the right shows how the habitat may be partitioned into four separate chambers. In this configuration, self contained AEM style water dispensers and food bars are used in supplying food and water to the individually housed rodents.

SPECIMEN CHAMBER CONFIGURATIONS

GANG HOUSED
[MAX. OF 6 RATS]
AREA = 204 SQ. IN.

2 INDIVIDUALLY HOUSED RATS
AREA = 102 SQ. IN./ RAT

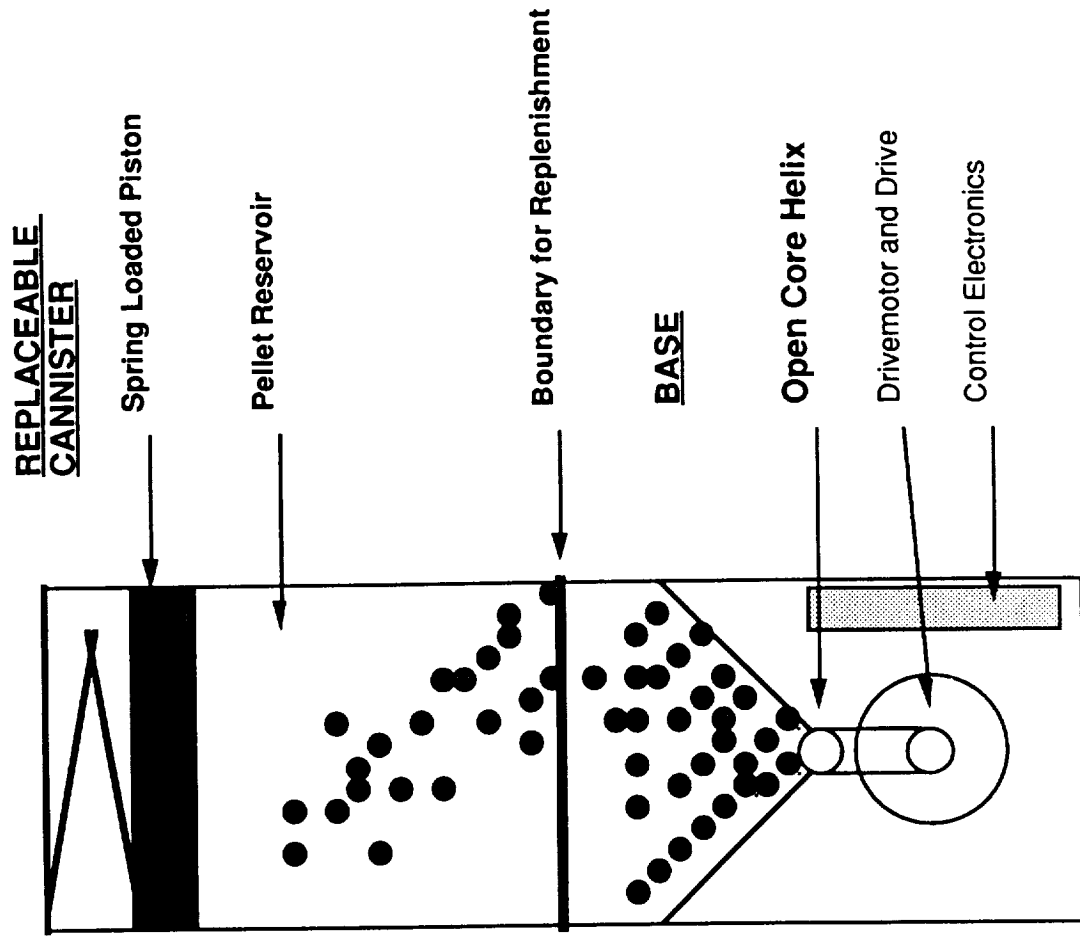
4 INDIVIDUALLY HOUSED RATS WITH
OPTIONAL FEEDER/WATER
DISPENSER SYSTEMS
AREA = 42 SQ. IN. / RODENT



HABITAT CHARACTERISTICS

One of the design objectives was to use a high density pellet storage cannister which did not require cumbersome pre-loading. The rodent feeding system which was chosen is based on an experimental high density pellet dispenser under development at ARC. The accompanying sketch shows the major elements of this design. First, a replaceable cannister uses a spring loaded piston to push the pellets into a hopper and in turn into an open core helix. As the animal specimen taps an actuating switch, the small motor turns the open core helix which drives pellets to a sensing mechanism (light or mechanical switch) which detects when a pellet has been ejected.

PELLET FEEDER CONCEPT

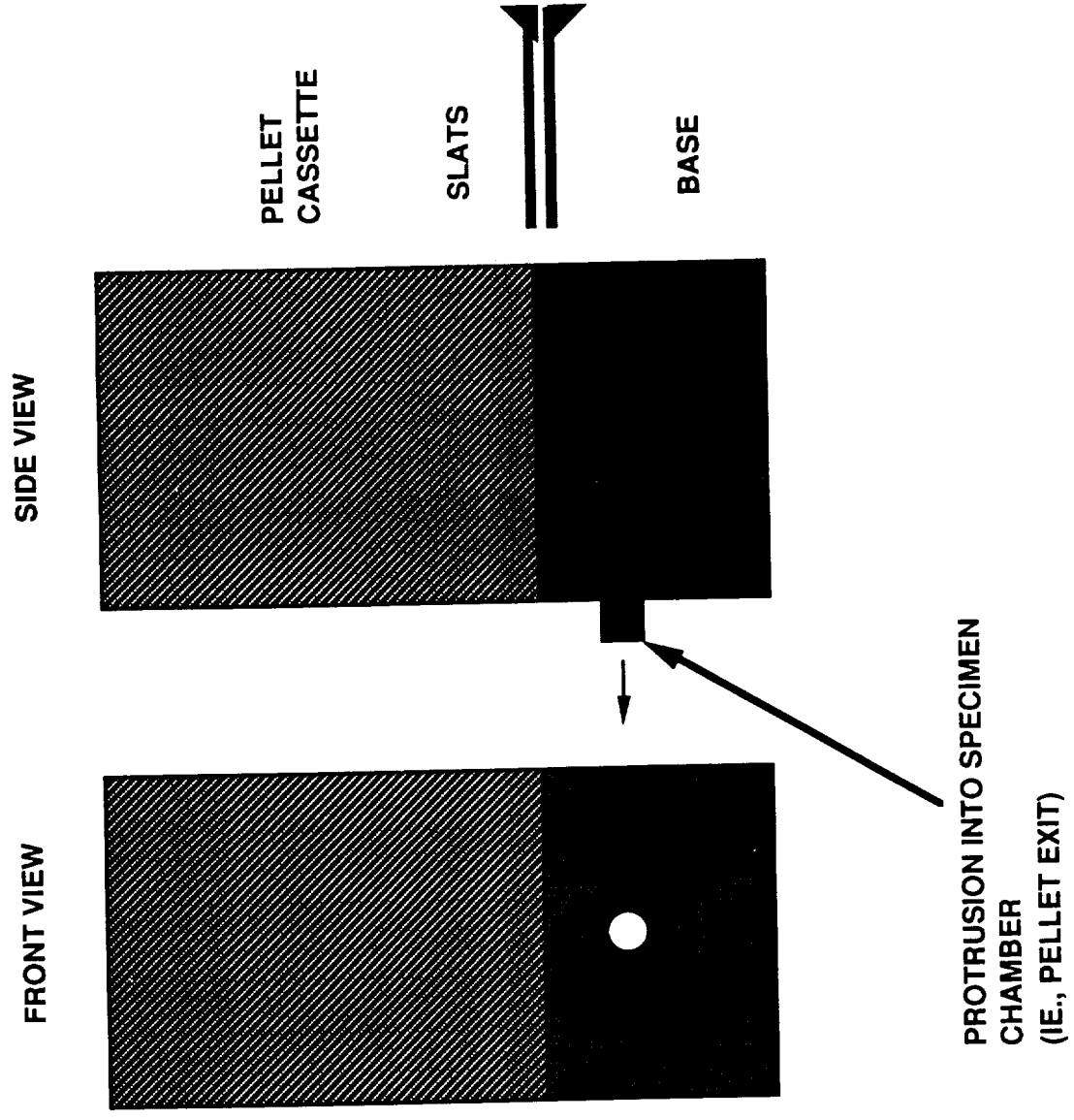


HABITAT CHARACTERISTICS (CONT'D)

The external view of the high density pellet feeder is shown on the facing page. The pellet cassette is replaced by first pulling the top spring-loaded piston away from the remaining pellets. This enables two slats to be inserted between the pellet cassette and the base to trap the pellets in the cassette and base (hopper). The depleted cassette is then replaced with a new one. Once in place, the two slats are removed and the feeder is again functional.

The only element of the dispenser which protrudes into the specimen chamber is a front tube-like element housing the end of the open core helix. A gasket seals the specimen chamber wall at the feeder, preventing leakage into the specimen chamber receptacle. The feeder is designed to direct the pellets in a desired direction and to prevent the animal specimen from injuring itself.

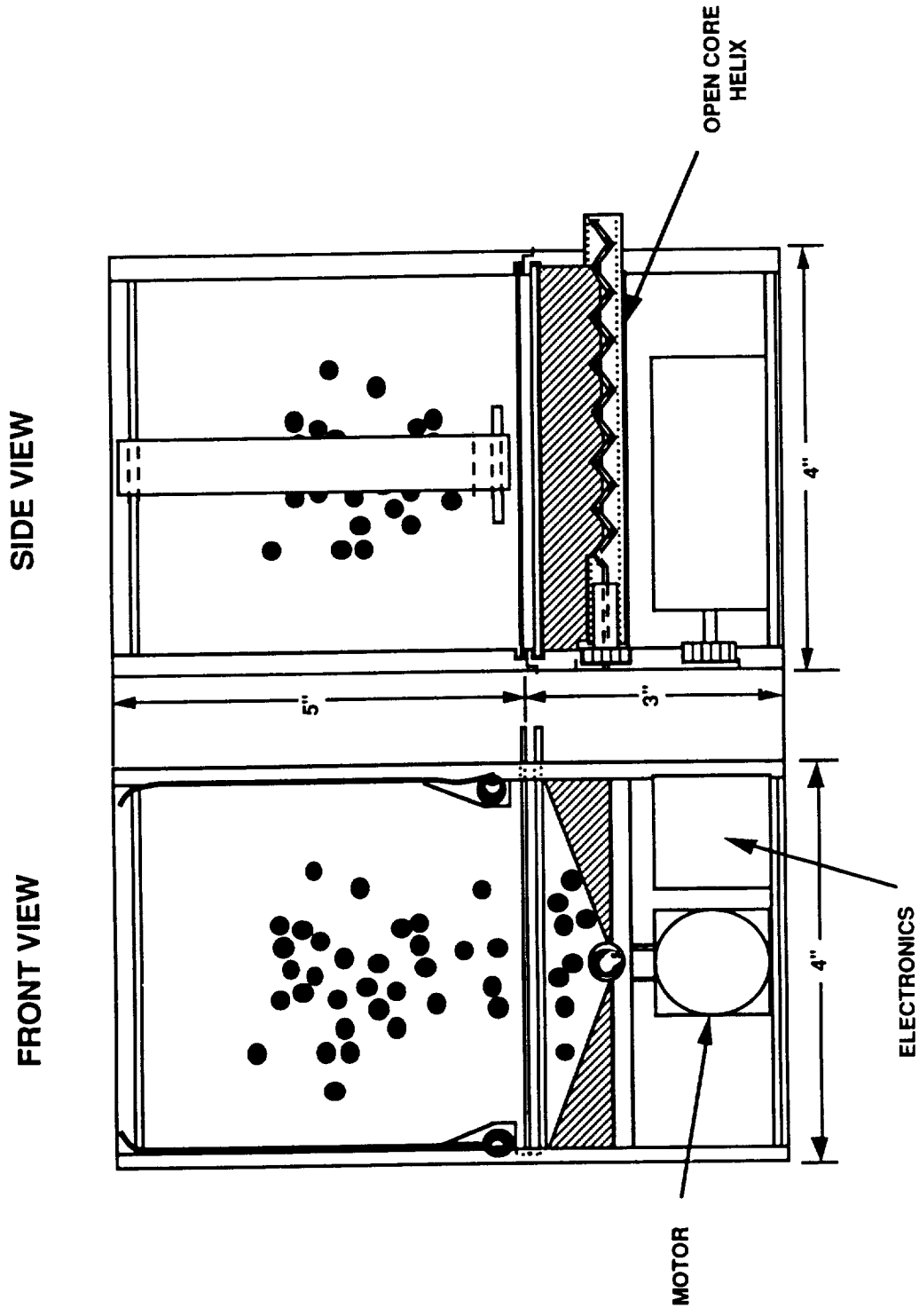
PELLET FEEDER CONCEPT (CONT'D)



HABITAT CHARACTERISTICS (CONT'D)

A drawing of the high density pellet feeder concept is provided on the facing page. The primary mechanisms within the feeder are as follows. A constant force spring forces pellets into the helix (delivery mechanism). The hopper dimensions affect the ability to force pellets into the helix. The helix in this configuration agitates the local pellets and prevents any bridging which would otherwise occur. The helix is operated by a small dc stepper motor which can reverse itself if a stoppage is detected (via stepper motor voltage). The open core helix is the key to this concept. Unlike an auger (i.e., a solid core screw), the open core helix is able to deliver one pellet at a time through the tube-like structure which leads to the specimen chamber. It was found that the helix geometry is a critical design parameter and would need to be optimized.

PELLET FEEDER CONCEPT DETAIL



HABITAT CHARACTERISTICS (CONT'D)

In the following tables, estimates for mass and power are provided. The terms used under the basis column are as follows:

- 'est' - indicates an estimate based on rough calculations, existing hardware and catalog entries.
- 'cat' - the design concept hardware is similar to hardware in a current catalog.
- 'calc' - the design concept hardware estimates are calculated from known functions of dependent variables.

The habitat mass estimates are provided on the following page. Whenever possible, the subsystems used in RAHF and AEM were used to estimate the given numbers. For reference, the fully loaded AEM, which is 5 cm (2") shorter than the baseline Rodent Habitat, has a total mass of 27 kg (60 lbs) when fully loaded.

HABITAT MASS ESTIMATE

| <u>Item</u> | <u>Mass kg (wt. lbs)</u> | <u>Basis</u> |
|----------------------------|--------------------------|--------------|
| Basic Unit | 13.6 (30) | est |
| Water system | 4.5 (10) | est |
| Filter material | 4.5 (10) | calc |
| Electronics/data/fan/video | 1.1 (2.5) | calc |
| ECS sensors | 1.1 (2.5) | est |
| Light | 1.1 (2.5) | cat |
| Food | 4.5 (10) | calc |
| Food dispenser | 1.1 (2.5) | est |
| SUBTOTAL MASS | 32 (70) | |
| Contingency (25%) | 8 (18) | |
| TOTAL MASS | 40 (88) | |

HABITAT CHARACTERISTICS (CONT'D)

The power estimates for the Rodent Habitat are listed on the facing page. The estimated power required for the Rodent Habitat is dominated by the lighting subsystem needed to illuminate the bottom of the specimen chamber at 100 lux. Heat dissipation is accommodated by the secondary air loop described earlier.

ESTIMATED POWER

Power-watts

| <u>Item</u> | <u>Average</u> | <u>Peak</u> | <u>Basis</u> |
|------------------|----------------|-------------|--------------|
| Food delivery | 0 | 5 | est |
| Water system | 0 | 5 | est |
| Lighting | 20 | 40 | cat |
| Cooling fan | 2.5 | 2.5 | cat |
| Air Heater | 5 | 5 | cat |
| Electronics/data | 7.5 | 7.5 | est |
| Video (2) | 8 | 8 | est |
| Total | 43 | 73 | |

Heat rejection rate to the cabin air is 38 watts average and 68 watts peak

SYSTEM INTERFACES

The interface requirements between the habitat and other facility systems greatly affect the orientation and internal geometry of the Rodent Habitat design.

The Rodent Habitat has two standard system interfaces. A standard interface on the rear of the habitat connects the habitat to the Holding System , Centrifuge, or Glovebox to provide resource lines. These resources include power, data, water, and respiration air. Cabin air enters and exits from the front of the habitat to cool the electronics. This air does not interface with the respiration air.

A standard interface on the habitat top connects the habitat to the Glovebox work volume. This interface is critical to access the specimens and the habitat subsystems. Both interfaces must maintain bioisolation with the cabin environment.

SYSTEM INTERFACES

Two standard System Interfaces

I.Holding System or Centrifuge Interface

- Standard Interface at rear provides
 - Power
 - Data interface
 - Water
 - Air

II.Glovebox Interface

- Standard Interface at rear provides
 - Power
 - Data interface
 - Air
- Glovebox access from interface at top

RODENT HABITAT TRADEOFFS

An outline of the tradeoffs which were considered in the Rodent Habitat design is presented on the facing page; the tradeoffs are explained subsequently. The tradeoff results are presented in terms of advantages (+) and disadvantages (-). The + and - symbols are qualitative and are not to be tallied to determine the quantitative merits of each option.

RODENT HABITAT TRADEOFFS

- Food System
- Water Delivery System
- Water System Sterilization
- Lighting Configuration
- Environmental Control System (ECS)
- Waste Collection System

RODENT HABITAT TRADEOFFS

A summary of the food delivery trade-off study is shown on the facing page.

Although food dispensers using a chain or bandolier delivery mechanism are currently available, they require a significant volume. As an alternative, foodbars present the best storage efficiency and the least number of delivery mechanisms, but it is difficult to accurately measure the quantity of foodbar consumed by specimens. Foodbars were used in rat experiments on the Spacelab Research Animal Holding Facility and the Animal Enclosure Module.

Overall, it is a difficult task to construct a cassette type feeder that could be loaded and unloaded easily without use of the Glovebox while maintaining two levels of bioisolation. In particular, the above goal is even more difficult if the simplicity of the specimen chamber is not compromised. For these reasons, the helical feeder was chosen as the most attractive candidate. It is evident, however, that some effort must be expended in the development and test of this concept and more effort given in the pursuit of other concepts.

RODENT HABITAT TRADEOFFS

Food System Tradeoff

| Foodbar | Chain Feeder | Bandolier | Helical Feeder |
|----------------------------|--------------------------|--------------------------|--------------------------|
| - Inaccurate food metering | + Accurate food metering | + Accurate food metering | + Accurate food metering |
| + Best packing density | - Worst packing density | - Fair packing density | + Good packing density |
| - Changed in Glovebox | + Glovebox not required | + Glovebox not required | + Glovebox not required |
| + Mature technology | + Mature technology | - Untested | - Untested |
| + Low complexity | - High complexity | - High complexity | - Medium complexity |

Current Choice: The Helical Feeder is adopted as a baseline with the Bandolier Feeder as an option. A default option is the Foodbar.

RODENT HABITAT TRADEOFFS (CONT'D)

A summary of the tradeoffs between a plumbed water system and a reservoir water system is provided on the facing page.

In a plumbed water system, water is plumbed to a small daily supply reservoir. The concept is similar in some respects to the RAHF watering system except that the reservoir and metering elements are located in the habitat.

In a reservoir water system, a sufficiently sized reservoir supplies water to the rodents for 14 days. Among the advantages that this system has over other systems are: it is a flight rated system (i.e., a similar system was flown on the AEM mission), it requires less plumbing, and it provides good monitoring accuracy. Disadvantages include volume and weight penalties.

A plumbed water system with a small contingency reservoir has been chosen as the baseline water delivery system for the Rodent Habitat.

RODENT HABITAT TRADEOFFS (CONT'D)

Water Delivery System Tradeoff

| Habitat Reservoir | Plumbed System |
|--|-----------------------------------|
| - Disturb Centrifuge balancing | + Little effect on Centrifuge |
| - Reduces chamber volume | + Little effect on chamber volume |
| - Difficult to meter over small time scale | + Improved metering |
| + Simplicity of operation | - Complexity of operation |
| + Reduction in plumbing | - Plumbing required |
| + Eliminates need for flow for sterilization | - Needs flow for sterilization |

Current Choice: Plumbed water system with small contingency reservoir.

RODENT HABITAT TRADEOFFS (CONT'D)

A summary of the water sterilization system tradeoffs between an iodinator and an ultraviolet system is presented here.

Although more operationally complex, an iodinator system is a mature design and was used in the RAHF program. Conversely, an ultraviolet system is less complex but requires further development. Furthermore, an ultraviolet system may be more volume efficient than an iodinator system. However, much depends on the water quality that is provided by Space Station Freedom and other system considerations. The iodinator is the preferred option, but is not shown in the initial baseline design.

RODENT HABITAT TRADEOFFS (CONT'D)

Water Sterilization System

| Iodinator | UV System |
|---------------------------------|-----------------------------------|
| - Depends on chemical dispenser | + Independent of chemicals |
| - Operationally more complex | + Operationally simpler |
| + Mature RAHF technology | - Requires technology development |

Current Choice: RAHF developed iodinator with growth option to UV system.

RODENT HABITAT TRADEOFFS (CONT'D)

An incandescent lighting system cannot supply the desired 100 lux intensity without penalties in both power and in the required cooling system design. Therefore, fluorescent lighting was chosen for the Rodent Habitat baseline design. The lighting subsystem placement tradeoffs summary is shown on the facing page.

By locating the lighting system in the Holding Unit, a major habitat subsystem is removed from the habitat at the expense of a more complex interface with the Holding Unit. This helps simplify the habitat design and thermal control subsystem. However, one common lighting system at the rack is inappropriate since the plant, rodent and monkey habitats have different lighting requirements.

Locating the lights in the housekeeping zone compromises the specimen chamber volume and results in non-uniform illumination across the chamber floor.

Because the lid must be removed to service the habitat, locating the lights within the lid will increase servicing complexity; the lights require additional connections between the habitat and lid. Despite the added complexity, locating the lights in the lid provides the most spacious living chamber for the animal and the most uniform chamber illumination of the 3 alternatives. For these reasons, the lighting system was located in the lid for the baseline design.

RODENT HABITAT TRADEOFFS (CONT'D)

| Lighting System Tradeoffs | | |
|---|---|--|
| In Holding Unit | In Habitat Housekeeping Zone | In Habitat Lid Zone |
| <ul style="list-style-type: none"> + Removes major component from habitat + Easiest to cool - Greater transmission losses through window - Requires common lighting system for all habitat types - Requires lighting in on-orbit transporter + Increases potential chamber volume + Minimum interference during habitat servicing - Complex interfaces with habitat | <ul style="list-style-type: none"> + Removes major component from lid + Easy to cool + Reduces transmission losses through window + Individual habitat lighting system + No lighting in on-orbit transporter - Reduces chamber volume - Possible interference during habitat servicing | <ul style="list-style-type: none"> - Major component in lid - Most difficult to cool + Reduces transmission losses through window + Individual habitat lighting system + No lighting in on-orbit transporter - Reduces chamber volume - Interferes with habitat servicing |
| <p>Current Choice: Location in Lid Section is compromise with least effect on habitat chamber volume. However, this imposes interference for servicing.</p> | | |

RODENT HABITAT TRADEOFFS (CONT'D)

A strip heater is used to control the temperature inside the habitat. As shown on the following table, three heater locations were considered. The lid was selected as the best location based on volume considerations.

RODENT HABITAT TRADEOFFS (CONT'D)

Heater Location Tradeoffs

| Inlet Air Duct | Holding Unit | Habitat Lid |
|--|------------------------------|---------------------------|
| + Relatively high transport velocity and good mixing | + Removes component from lid | - Added complexity to lid |
| - Limited volume in duct | - Limited volume in duct | + Adequate volume |

Current Choice: Locate heater in lid of habitat.

RODENT HABITAT TRADEOFFS (CONT'D)

The humidification system is used to increase the relative humidity (RH) level inside the habitat. This is accomplished by injecting small quantities of water into the respiration air upstream from the specimen chamber. Two approaches were considered: an atomizer system and a wick system.

An atomizer system located in the respiration air line would rely on a constant water pressure external to the habitat. This water source would connect to the atomizer with a control valve to control the period over which humidification took place.

The wick system uses a modified water metering unit already in the housekeeping section to control the amount of water delivered to a wick in the specimen chamber. Upon its evaporation, the relative humidity average inside the specimen chamber would increase. This system was chosen as the baseline design over the atomizer because of its operational simplicity and volume efficiency.

RODENT HABITAT TRADEOFFS (CONT'D)

Humidification System Tradeoffs

| Wick | Atomizer |
|--|--|
| <ul style="list-style-type: none"> + Uses drinking system metering device - Slow response time + Sterilization supplied by drinking system + Independent of rack water pressure - Possible microbial growth on wick | <ul style="list-style-type: none"> - Requires separate water system + Quick response time - Separate water sterilization system required - Dependent on rack water pressure - Possible microbial growth within atomizer |

Current Choice: A wick system which uses the drinking water metering and sterilization system .

RODENT HABITAT TRADEOFFS (CONT'D)

A properly designed waste collection system is recognized as critical to the development of a functional rodent habitat. Mechanical and electrical means of removing waste from the specimen chamber were precluded due to relative complexity and potential unreliability. Though operationally limited, a passive waste entrainment system operating at low air flow rates has been selected as the baseline design. Studies to explore alternative waste collection techniques and ways to improve the baseline design are being performed. The waste tray is located at the bottom of the specimen chamber as shown in earlier sketches.

A disposable chamber may reduce the cleaning operations that a washable chamber would otherwise require. The current baseline specimen chamber design would work well with either option due to its simplicity. The tradeoff between disposable and washable specimen chambers is discussed in greater detail in the Specimen Chamber Service section.

RODENT HABITAT TRADEOFFS (CONT'D)

Waste Collection System

| | |
|-------------------|--|
| Type: | Air flow system, even at low flow rates, is considered the only viable option. |
| Location: | Waste tray location on 'side' of habitat considered but location on bottom selected as baseline. |
| Specimen Chamber: | Disposable vs. Washable specimen chamber discussed in Specimen Chamber Service Unit chapter. |

RODENT HABITAT TRADEOFFS (CONT'D)

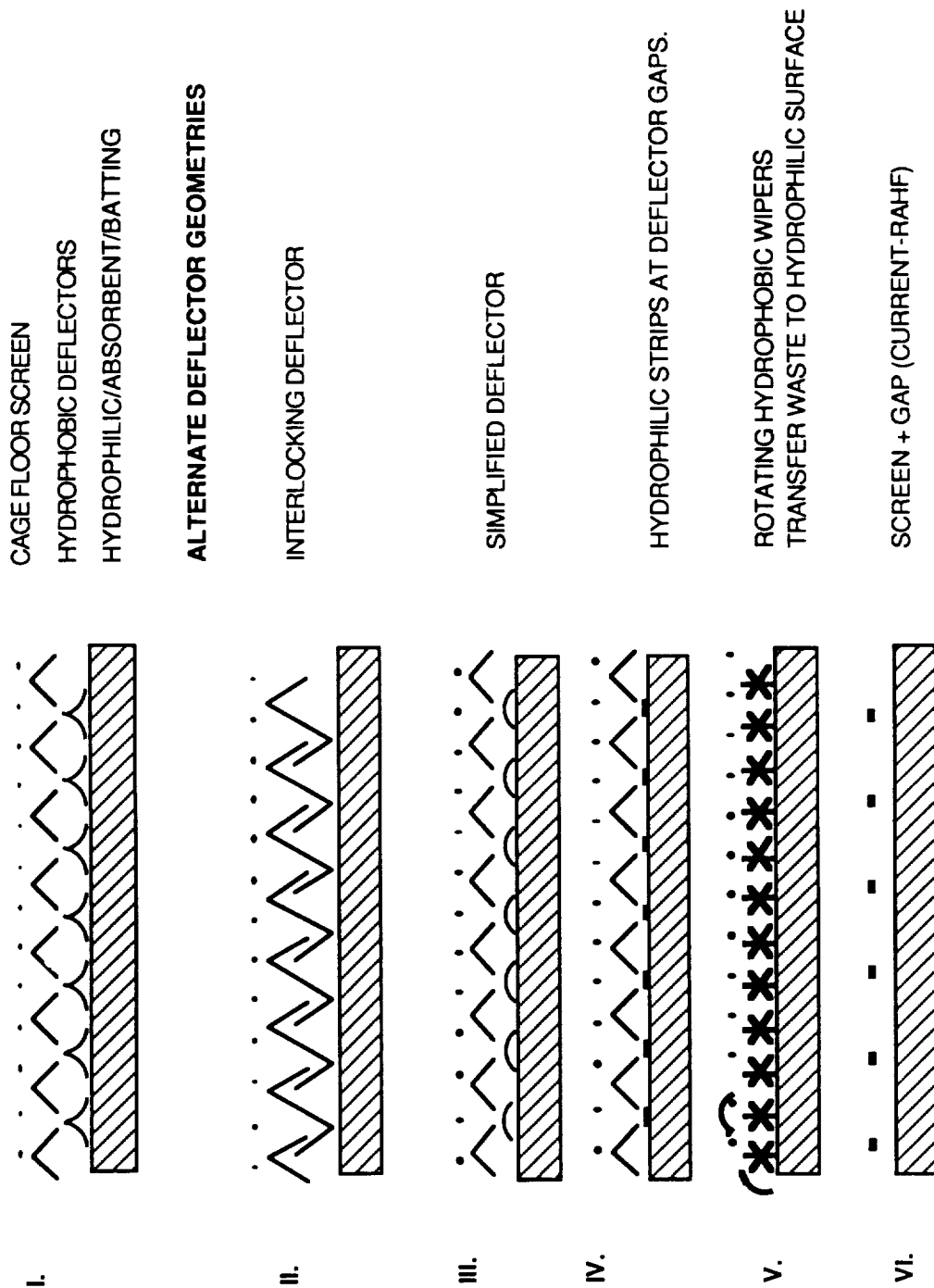
The waste collection concepts are presented on the facing page. Designs I through IV represent various passive waste collection systems which utilize a hydrophobic deflector and hydrophilic/absorbent material. The solid and liquid waste from the specimens is gradually drawn through the deflectors which help to prevent the waste from reentering the specimen chamber. Figures (I-IV) show a variety of deflector geometries. A test program would be required to determine the suitability of a particular design.

Concept V is representative of the active waste collection methods which were considered. In this case, a system of rotating wipers which move at periodic intervals deposit the waste onto a hydrophilic surface.

A rat waste tray from RAHF (Research Animal Holding Facility) is shown as concept VI. Because there are no deflectors with which to capture waste, waste reenters the habitat when the habitat is subjected to accelerations (i.e., from moving the cage from one location to another).

In general, the passive waste collection systems which included a means of preventing the waste from reentering the specimen chamber were regarded as the most attractive approach. While improving on the relatively simple RAHF system, concepts I-IV did not have the disadvantages associated with active waste collection designs. For these reasons, the passive deflector waste collection system was chosen as the baseline concept.

WASTE COLLECTION CONCEPTS



OPERATIONAL SCENARIO

The operational scenario of a typical Rodent Habitat transfer is provided on the facing page.

OPERATIONAL SCENARIO

1. Habitat is removed from Holding Unit or Centrifuge
2. Habitat is mounted to one of two Glovebox bays
3. The habitat external lid is removed within Glovebox
4. The habitat access lid is disconnected and removed, exposing the top of the specimen chamber
5. The specimen chamber top may now be removed, exposing the specimens
6. The specimens are now placed in the awaiting clean habitat in the adjacent bay
7. The dirty specimen chamber is cleaned
8. The specimens are transferred into the clean specimen chamber or carried in the second habitat back to either the Holding Unit or Centrifuge

DESIGN CHALLENGES

Several major design challenges were identified during the design process.

The first challenge is to meet the floor space and volume requirements for animal accommodations. The concept defined in this study provided 1300 cm² (204 cm²) of floor space to accommodate at least 6 rats based on the phase B study specifications and less than 3 rats based on National Institute of Health (NIH) specifications. The difference in floor space required between the NIH guidelines and the Phase B Statement of Work will be reconciled through studies at ARC to verify housing requirements for rodents at μ g.

The second challenge is associated with the air flow rate which is driven by a combination of thermodynamic, waste collection, bioisolation, and hardware sizing issues. A high air flow system of 28,300 cc/s (60 CFM) requires a significant amount of energy to cool to the inlet set point and heat to the desired temperature. A low air flow system 470 cc/s (1 CFM), on the other hand, is less effective for waste entrainment. For comparison, the RAHF and AEM have air flow rates of approximately 3,300 cc/s (7 CFM).

Two alternatives may alleviate the problems associated with waste collection and with system airflow. One alternative temporarily increases the air flow via a fan in the habitat. This poses a problem in that one level of bioisolation could be compromised if pressure levels within the habitat exceed the ambient pressure. The second alternative uses the main blower of the Holding Unit to temporarily increase the air flow. Both of the concepts require further studies.

DESIGN CHALLENGES

- Specimen Accommodation
 - NIH guideline 450 cm² (70 in²) per rat difficult to meet for 4 rats
 - Phase B Specifications require 271 cm² (42 in²) per rat
1084 cm² (168 in²) for 6 rats
 - Guidelines for μ -g are not yet verified
 - Size and number of rodent specimens may be compromised
- Air Flow System
 - Low velocity flow is less effective in waste entrainment
 - Low velocity increases likelihood of stagnant zones in habitat

DESIGN CHALLENGES (CONT'D)

Routine maintenance such as sensor servicing, food cassette replacement, and specimen chamber servicing will require crew time which is a scarce resource. Therefore, the goal of the design must be to reduce crew time requirements.

Sensor location within the habitat affects maintainability and thus crew time. Sensor positions should not impede disassembly and subsequent servicing operations.

The food system required to feed 6 large rats for 14 days was large. As a compromise, the food system size could be reduced and the interval between food cassette servicing decreased.

DESIGN CHALLENGES (CONT'D)

- Experiments and Servicing
 - Crew time is a scarce resource
 - System design must facilitate maintenance and operation
- Sensors
 - Sensors may complicate internal walls of specimen chamber making it more difficult to clean, service and maintain
 - Sensor location should not hinder servicing operations
- Food servicing
 - Food system for 6 rats is large
 - May compromise service intervals

DESIGN CHALLENGES (CONT'D)

A challenge in the food delivery system design is to produce a dependable device which reduces crew involvement while maintaining the required bioisolation.

The waste collection system greatly affects Rodent Habitat serviceability. The maintainability of the specimen chamber and its associated elements will be a key indicator of a satisfactory design. The air flow and other factors affecting waste entrainment must be thoroughly tested prior to flight.

DESIGN CHALLENGES (CONT'D)

- Feeding Mechanisms
 - Location in housekeeping zone implies that food cassette must penetrate 2 layers of bioisolation to reach internal specimen chamber
 - Externally serviced food cassette difficult to design
 - Current systems are either inadequately metered (food bar) or are too voluminous (chain pellet feeder)
- Waste Collection
 - Design affects specimen chamber volume and crew service time
 - Walls, windows and instruments may become coated with waste
 - Sample collection of urine and feces outside the Glovebox will require unique specimen chambers and habitats.

REQUIREMENTS NOT MET

The habitat design as shown herein will accommodate 3 rats according to the NIH guidelines and 6 rats based on the Centrifuge Facility Phase B specifications. ARC is attempting to better define specimen chamber sizing requirements for rats in the μ -g environment.

The requirement to control temperature while maintaining the relative humidity within the required bounds will be difficult to meet. More detailed analysis and testing will be required to verify that this requirement can be met particularly when considering uncontrolled water additions from the animals.

The baseline design uses fluorescent bulbs which do not permit the desired 5-100 lux variability. Moreover, the transmission of light through the light receptacle cover will gradually degrade as waste collects on the surface.

REQUIREMENTS NOT MET

- Number of specimens accommodated
 - NIH guidelines limit specimen chamber to 3 rats with 450 cm² (70 in²) per rat
 - Phase B specifications accommodate 6 rats in terms of volume allocated.
 - Actual requirements will require confirmations.
- Temperature/ Humidity control
 - 40-70% RH cannot always be met due to uncontrolled water addition
 - Water absorption may affect temperature, making it difficult to maintain $\pm 1^{\circ}\text{C}$.
- Light System
 - Energy efficient fluorescent bulbs do not permit 5-100 lux variability
 - Light levels will significantly degrade as waste collects on the light cover

TECHNOLOGY DEVELOPMENT

Design aspects of the Rodent Habitat which require some development are listed on the facing page.

ENVIRONMENTAL CONTROL

The ability to control the habitat's temperature and humidity to the desired accuracy is unknown. An airflow and environmental control testbed is being developed at ARC to study the thermal and humidity characteristics of the habitat under varying flow rates with water addition and evaporation. The results of this study should give a better understanding of the degree to which the environment within the habitat can be controlled.

WASTE MANAGEMENT SYSTEM

The design of an efficient waste management system is a challenge to be met in order to provide a living environment conducive to the animal health and well being. Work is underway to develop a special waste tray cover that would aid in the collection and containment of waste matter.

FOOD DELIVERY SYSTEM

An innovative design is needed for a programmable feeder that satisfies the monitoring accuracy (to $\pm 1\%$), and is volume efficient, mechanically simple, and gravity independent.

WATER TREATMENT AND METERING SYSTEM

Additional information about the water quality that Space Station provides and the placement of the water treatment system on the habitats, Holding Unit, or Centrifuge will help in selecting or designing the water treatment system.

TECHNOLOGY DEVELOPMENT

AREAS REQUIRING FURTHER DEVELOPMENT

1. Air flow system concepts (environmental control related)
2. Waste management
3. Accurate food dispensing
4. Water treatment and metering

SUMMARY

In summary, the Rodent Habitat baseline design meets most of the science requirements. The key design challenges are: number of specimens accommodated, environmental control within the desired accuracy, waste management system, reducing operations which require extensive crew involvement, and developing accurate and efficient food and water delivering systems.

On-going and future studies will research the feasibility of solutions to these design challenges.

SUMMARY

- Baseline design illustrates options and tradeoffs
- Baseline design satisfies most science requirements
- Design challenges include:
 - number of specimens accommodated
 - environmental control within desired parameters
 - waste management system
 - crew interaction
 - food and water metering system
- ARC to continue efforts on technology development

APPENDIX - ALTERNATE CONCEPTS 1-5

The alternate design concepts listed on the facing page demonstrate attempts to find the best layout for the Rodent Habitat. The first four concepts do not deviate much from the baseline concept. The final concept is unique. Figures which illustrate these concepts are shown on subsequent charts.

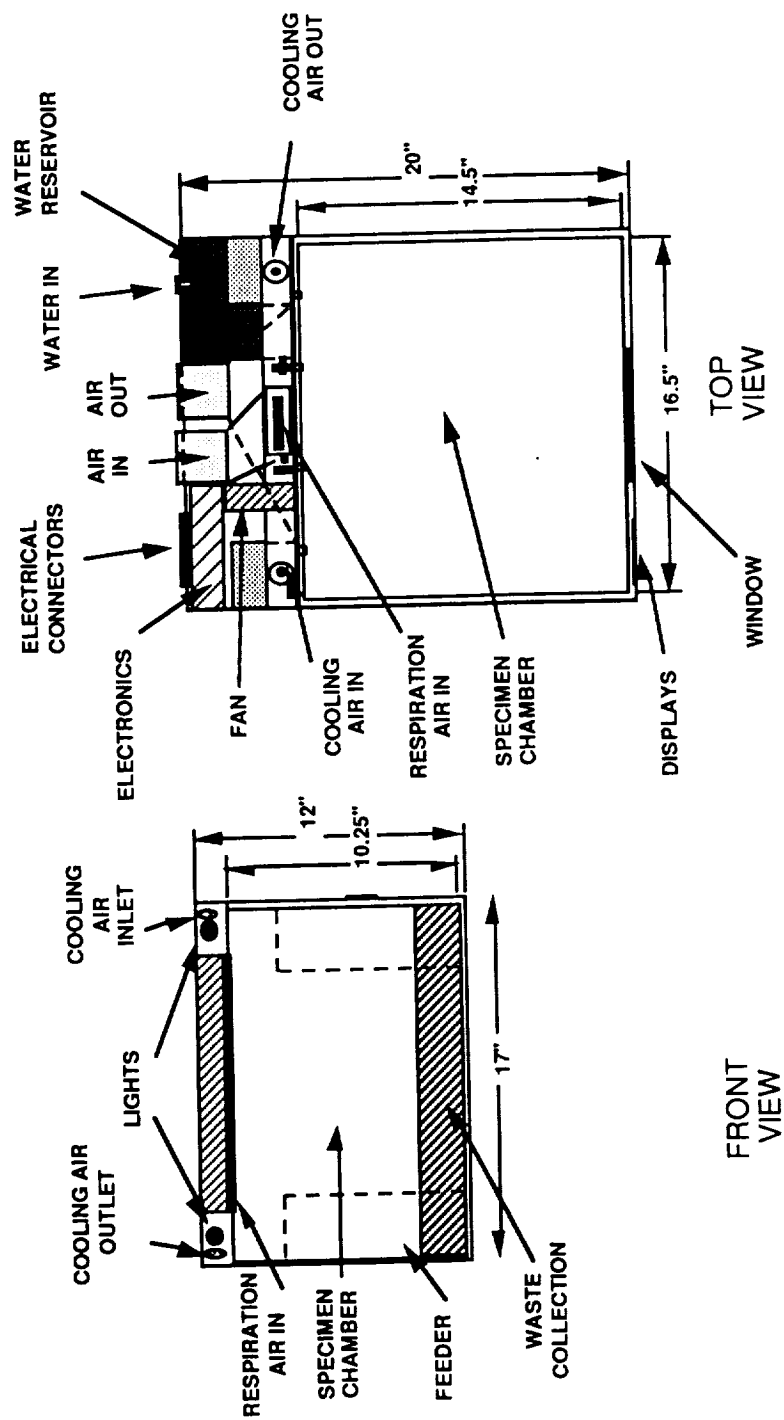
ALTERNATE CONCEPTS 1-5

- Alternate Concept 1
- Light bulbs are fixed on Habitat wall and not in Lid section
 - Water lixit opposite from feeder
 - Reduced Specimen Chamber volume
- Alternate Concept 2
- Light bulbs are fixed on Habitat wall and not in Lid section
 - Water metering system is in Habitat rear housing
 - Reduced Specimen Chamber volume
- Alternate Concept 3
- Split Housekeeping section
 - Feeder canisters replaced from front of Habitat
 - Water lixit opposite from feeder
- Alternate Concept 4
- Housekeeping section is combined in rear housing
 - Larger Specimen Chamber dimension
 - Cumbersome avionics air flow path
- Alternate Concept 5
- Funnel shaped specimen chamber
 - Rotating waste tray
 - Mechanical waste collection

ALTERNATE CONCEPT 1

Alternate concept 1 places the lighting system in the habitat housekeeping section and moves the food system to the front of the habitat for easier access. While this simplifies the lid section, it reduces the specimen chamber volume available and does not provide uniform illumination of the floor area. Moreover, the specimen chamber to habitat interface is more complex since protrusions from the food and water delivery system are on different walls. For these reasons, this concept was not selected as the baseline.

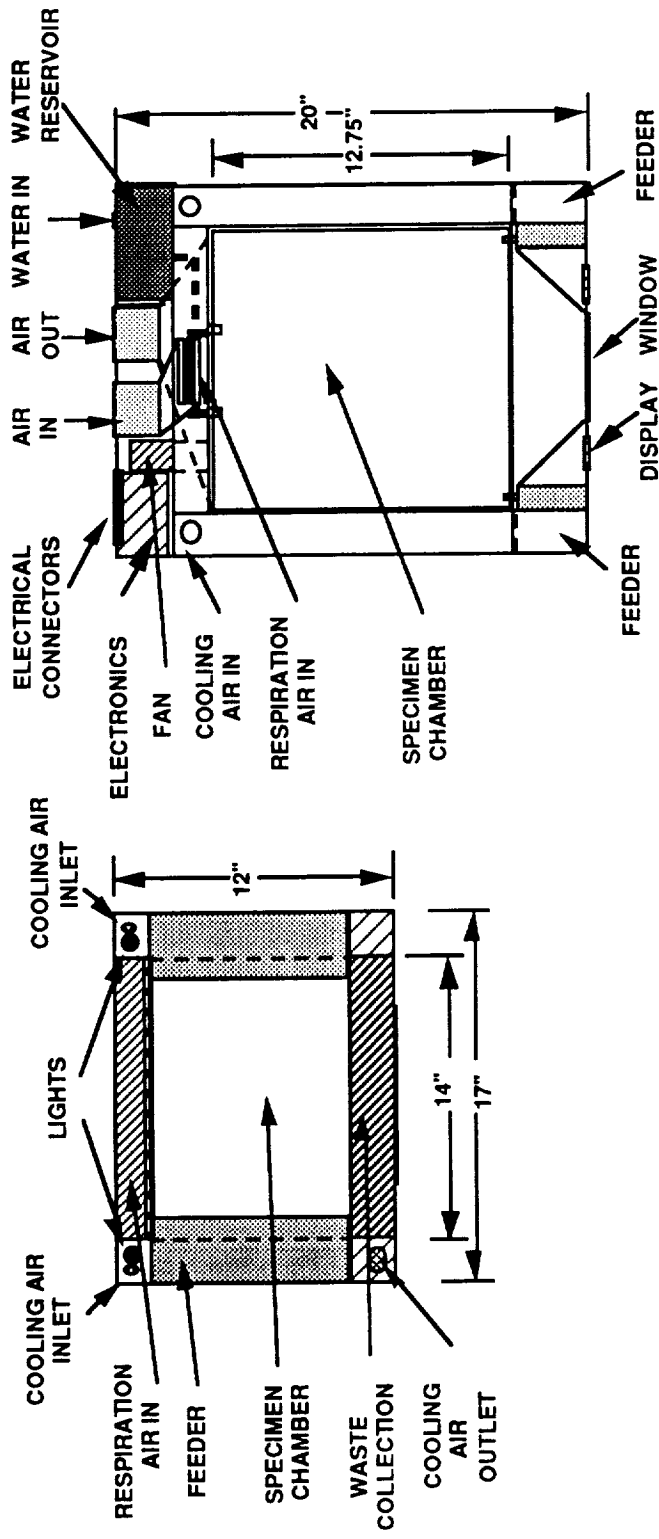
ALTERNATE CONCEPT 1



ALTERNATE CONCEPT 2

Alternate concept 2 also has the lighting system in the habitat housekeeping section. In this concept, the food delivery system was kept on one side of the habitat as in the baseline design, to keep the food/water interfaces on the same wall. The available specimen chamber volume is still less than that of the baseline design. Therefore, this concept was not selected as the baseline.

ALTERNATE CONCEPT 2



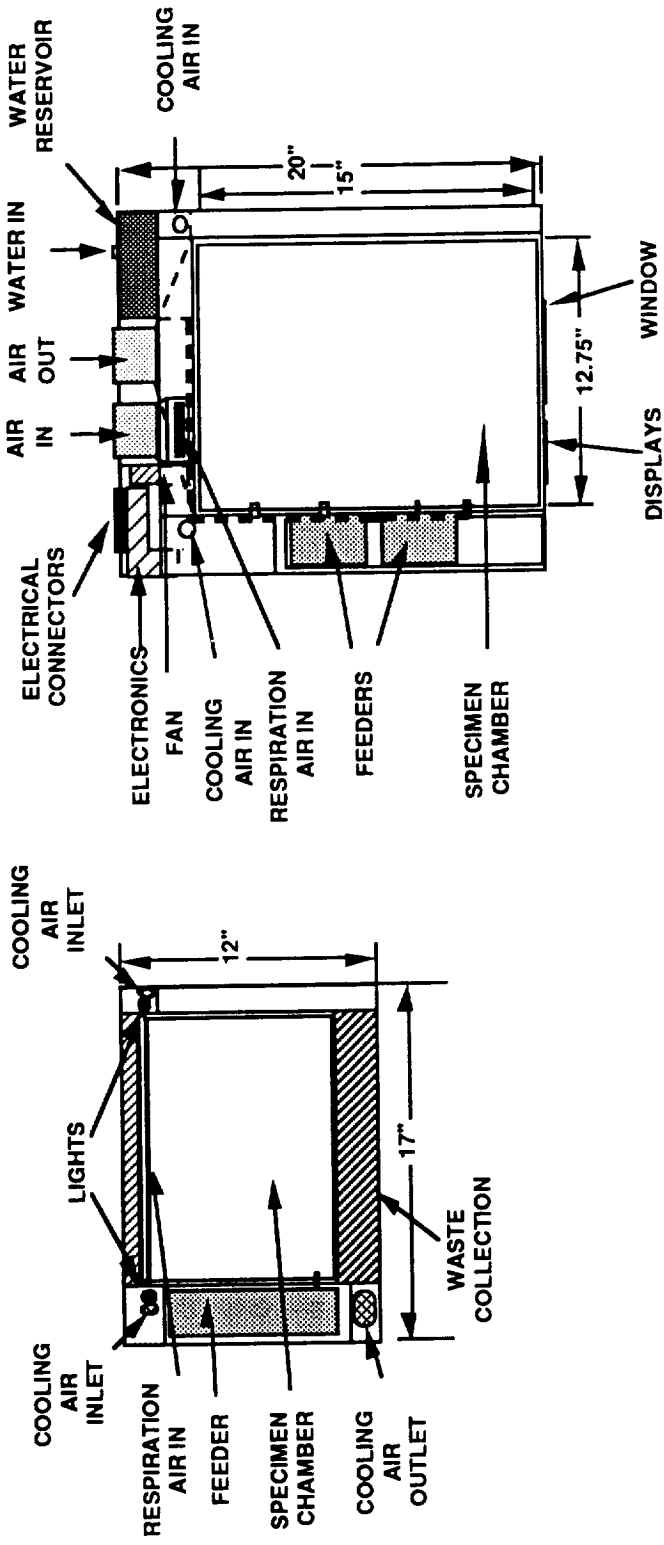
FRONT
VIEW

TOP
VIEW

ALTERNATE CONCEPT 3

Alternate concept 3 has the food system at the front of the habitat and the light bulbs placed in the lid. Though the specimen chamber volume is just as large as that of the baseline design, the specimen chamber to habitat interface becomes more complicated. Therefore, this concept was not selected as the baseline.

ALTERNATE CONCEPT 3



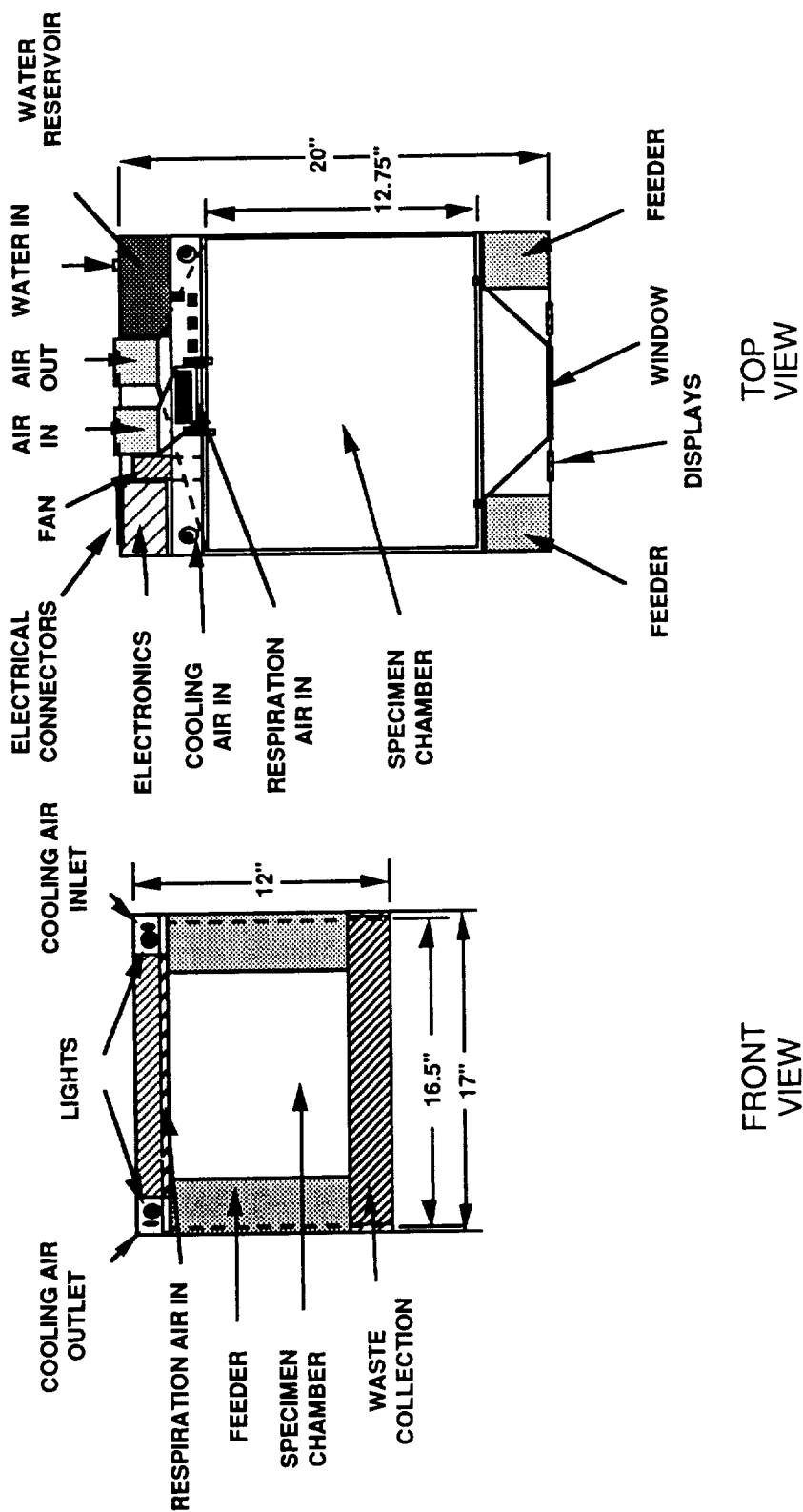
FRONT
VIEW

TOP
VIEW

ALTERNATE CONCEPT 4

Alternate concept 4 has all of the housekeeping functions in the rear section of the habitat. This results in more available specimen chamber volume, but separates the feeder into two sections. Therefore, this concept was not selected as the baseline.

ALTERNATE CONCEPT 4



ALTERNATE CONCEPT 5

Alternate concept 5 represents an innovative approach to solving the waste collection challenge. The specimen chamber is funnel shaped and constructed from hydrophobic materials. The rodent floor space is divided into two levels, the upper level acting as a tactile retreat. Waste matter is collected in a waste tray at the bottom of the 'funnel' in a manner similar to that used in the Biocosmos hardware. The waste is divided into pie shaped cells. Once every day the waste tray indexes one cell by rotating to allow waste to be collected for metabolic studies.

Among the concept's drawbacks are: 1) the split levels may not be appropriate on the Centrifuge due to difficulties in determining the long term radial distance from the specimens to the center of rotation; 2) the specimen chamber volume is compromised in favor of a potentially more functional waste collection system; 3) animal accessibility is reduced.

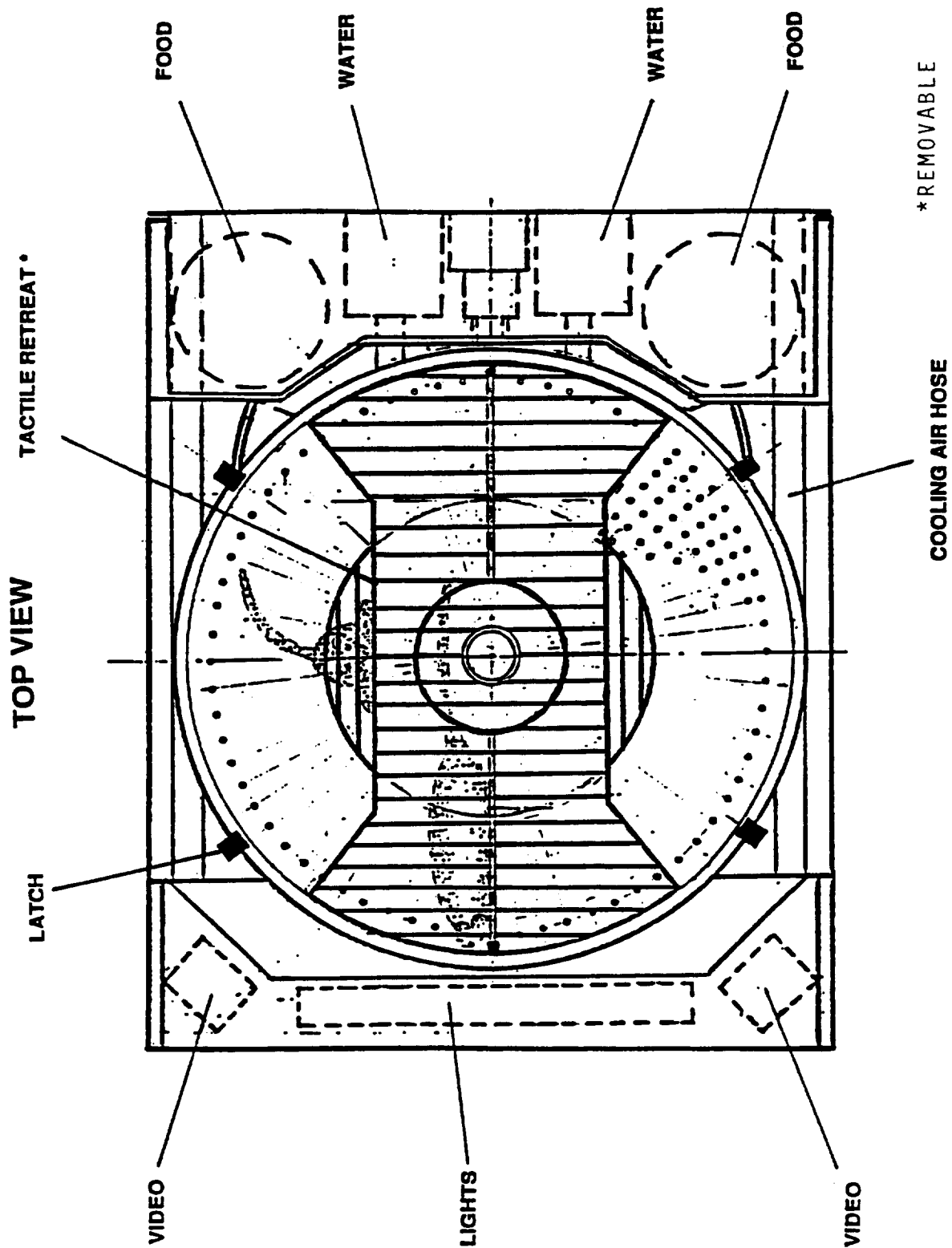
ALTERNATE CONCEPT 5

- Respiration air enters a circular plenum through a central filter at low velocity
- Air uniformly enters the conical specimen chamber via a perforated lid
- Air flow increases toward the lower section of the specimen chamber
- Air is forced at the bottom of the specimen chamber into an 8-cell rotating waste tray
- Tray drive turns waste tray at periodic intervals, exposing an empty cell
- Air distributor has a special hole arrangement to air dry the used cells
- Optional helical cleaning blade would assist waste collection by forcing the waste downward

ALTERNATE CONCEPT 5

The top view of alternate concept 5 is depicted on the facing page. The specimen chamber is funnel shaped as will be shown in a subsequent figure. The funnel shaped specimen chamber is shown by the concentric rings in the center of the diagram. The various subsystems are placed in areas about the specimen chamber itself. The chamber may be subdivided such that two rats may be individually housed.

ALTERNATE CONCEPT 5

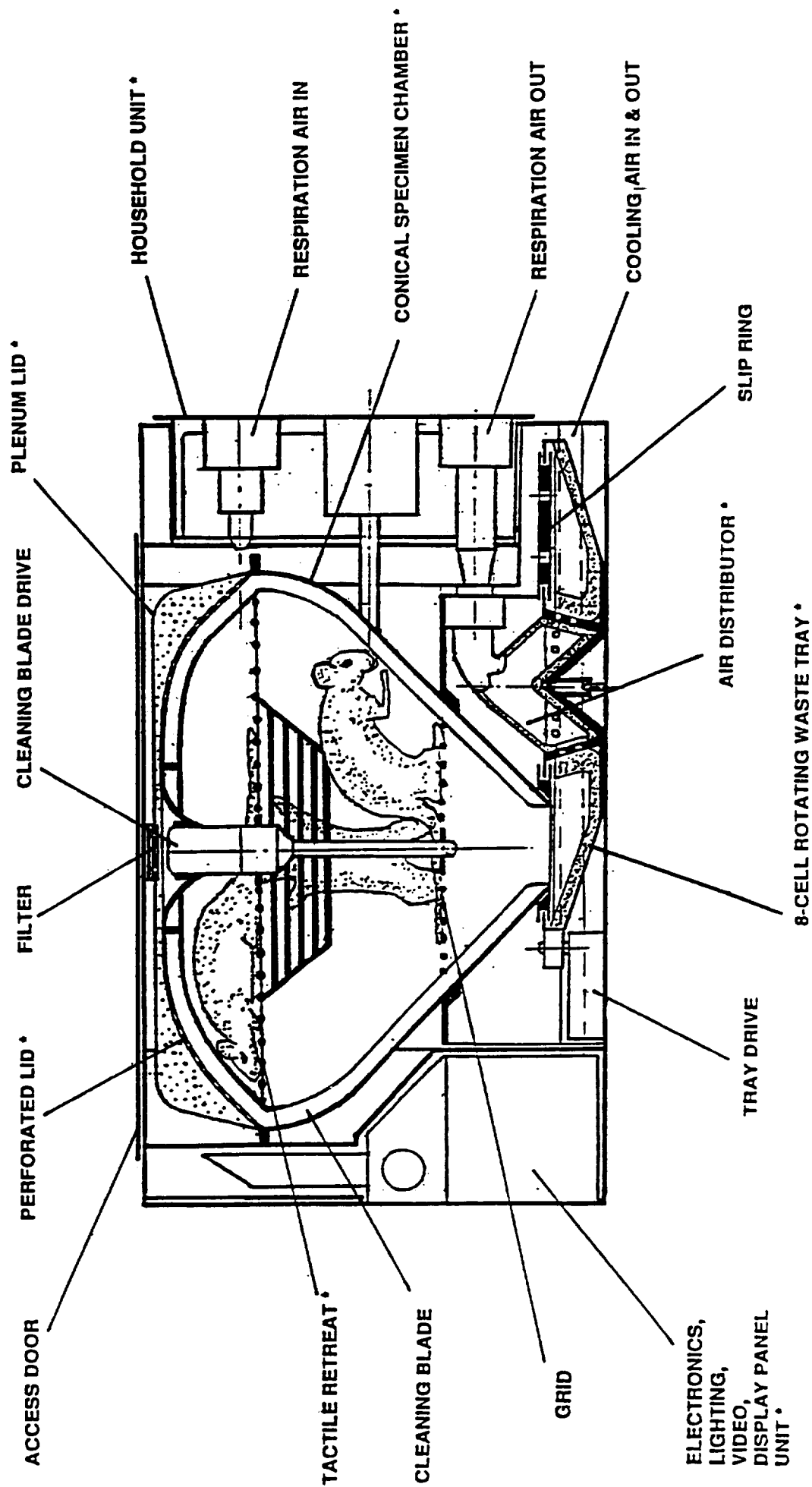


ALTERNATE CONCEPT 5

The side view of alternate concept 5 is depicted on the facing page which shows the split level funnel shaped specimen chamber. The split level is accessed through a small ladder-like structure in the center of the specimen chamber. The upper level serves as a tactile retreat.

ALTERNATE CONCEPT 5

CUT-AWAY VIEW



* REMOVABLE

ALTERNATE CONCEPT 5

Despite the many apparent advantages with concept 5, it was not selected as a baseline design because of the reduction in specimen chamber volume and the apparent complexity associated with the waste collection system. However, the innovative approaches presented in this concept will be continued in efforts to develop a design concept which meets the design objectives.

ALTERNATE CONCEPT 5

Advantages

- Conforms to Facility interfaces (fits within modular habitat volume constraints)
- Possible improved air flow patterns and waste collection characteristics
- Periodic waste collection stored in separate cells in sealed tray
- Greater cleaning effectiveness of Specimen Chamber due to lack of corners
- Specimen Chamber may lend itself to stacking for a disposable design option

Disadvantages

- Reduced Specimen Chamber volume
- Electro-mechanical waste tray mechanism adds design and maintenance complexity

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 3

Squirrel Monkey Habitat

INTRODUCTION

This chapter describes designs for both a Restrained and Unrestrained Squirrel Monkey Habitat. The design for the Unrestrained Squirrel Monkey Habitat will be discussed first, followed by the Restrained Squirrel Monkey Habitat. Systems common to both habitats are described at the end of this chapter.

An outline of the Squirrel Monkey Habitat chapter for the system study is provided on the facing page.

SYSTEM STUDY OUTLINE

- Primary Requirements
- Unrestrained Monkey Habitat
 - Design Description
 - Tradeoff Studies
 - Operations Issues Summary
- Restrained Squirrel Monkey Habitat
 - Design Description
 - Tradeoff Studies
 - Operations Issues Summary
- Common Design Features
- System Characteristics
- Requirements Not Met
- Technology Development
- Summary
- Appendix
 - Operations
 - Perch Design Matrix
 - Orthographic Habitat Views

PRIMARY REQUIREMENTS

A list of the habitat's primary requirements and the degree to which the concept design meets them is summarized on the following pages. These requirements are from the Science Accommodation Requirements in Appendix B of the Centrifuge Facility Phase B Specification. The status legend indicates whether or not the design satisfied each requirement.

The requirement for illumination levels is based on the recommendations of NASA Technical Memorandum 101077 (Lighting Requirements in Micro-gravity - Rodents and Squirrel Monkeys) which sets the illumination lower limit at 250 lux for squirrel monkeys. The illumination higher limit of 1000 lux is chosen to permit later applications where greater light intensities may be required. The SWG established illumination increments of 250 lux within the range of 250 to 1000 lux, which would allow fluorescent lighting to be used in the design.

For the Unrestrained Squirrel Monkey Habitat, the 46cm (18") standing height requirement and the requirement to locate light fixtures in the top one-third of the specimen chamber were met by designing a chamfered roof. When restrained monkeys are placed in the Centrifuge, the habitat design must allow the animal to either be seated (acceleration vector pointing from head to toe) or laid on its back (acceleration vector pointing from front to back). This requirement could be satisfied with a dual-orientation chair in the animal restraint system.

Research has suggested that an enriched environment helps in sharpening the animal's cognitive process and in generating individual behavior patterns. To meet the requirement for environmental enrichment, a tap switch feeder which can be programmed to a variable or ad libitum delivery schedule has been incorporated into the design. However, the SWG desires other enrichment techniques to be considered in the habitat design. For these reasons, further efforts must be devoted to the design of this subsystem and this requirement is considered only partially met.

PRIMARY REQUIREMENTS

STATUS *

| | |
|--|---|
| • 250, 500, 750, 1000 lux illumination levels, ±20% uniformity within chamber | M |
| • 30 cm (12 in") minimum height within restrained monkey specimen chambers | M |
| • 46 cm (18 in") minimum height within unrestrained monkey specimen chambers | M |
| • Two orientations of restraint system | M |
| • Behavioral enrichment | P |

*Status legend: M=Met P=Partially met N= Not met U=Unknown

PRIMARY REQUIREMENTS (CONT'D)

In their natural habitat, the Squirrel Monkeys are exposed to relatively high humidity and temperature. To maintain the specimen's health over any extended period of time, the specimen chamber temperature and relative humidity level must not drop below 15°C nor 40% R.H. Random water addition (e.g., urine, water from lixits) and its evaporation may make it difficult to meet the relative humidity requirements. Also, the interaction between temperature, humidity, and system air flow velocities will make the temperature and humidity difficult to control.

Uniform airflow is required to eliminate pockets of dead air space inside the specimen chamber. It is currently unknown if this can be achieved at the low air flow rates used by the system.

Because exposure to intense noise levels can cause a variety of behavioral and physiological changes in animals, the acoustic noise level inside the specimen chamber should not exceed 73 db. This limit extends over the entire animal audible frequency range of 20 Hz to 40 kHz. Insulation against excessive acoustic noise was not addressed in this study. However, it should be addressed in future habitat studies as the effect of prolonged exposure to moderate noise levels is of concern.

Food consumption is a valuable indicator and measure for many biological studies. The actual amount of food consumed cannot be measured but the amount dispensed in a standard pellet form can be easily measured.

The waste collection system uses airflow to transport waste particles to a collection site. Once collected, waste particles are prevented from re-entering the chamber by a specially designed waste tray cover. Currently, it is not known whether or not the waste tray cover concept will be effective in containing waste particles during habitat transport or animal movements. Alternate concepts were not addressed in this study.

PRIMARY REQUIREMENTS (CONT'D)

| | |
|---|---------------|
| • Temperature controlled between 15-35°C ± 1°C | <u>STATUS</u> |
| • Air composition equivalent to Freedom cabin air | P |
| • Uniform airflow within specimen chamber | M |
| • Humidity maintained at 40-70% | U |
| • Acoustic noise less than 73 dB from 20 Hz to 40kHz | P |
| • Food consumption measured half-hourly to an accuracy of ± 1% (every half hour) | U |
| • Isolate collected waste | M |
| | U |

*Status legend: M=Met P=Partially met N= Not met U=Unknown

PRIMARY REQUIREMENTS (CONT'D)

A total of 20 data channels per specimen are required, with the flexibility to be configured to accept data either via hardwires from the animal to the habitat or telemetered via RF. The quantity of channels to be used will be determined by experiment protocol.

Daily collection of animal solid waste from restrained squirrel monkeys is required. The current habitat design requires use of the Glovebox for sample collection.

Visual access to the animal is to be provided via: color video monitoring, black and white video monitoring, infrared video monitoring, and windows ("unpowered visual monitoring"). This requirement is designed to allow both the crew and ground investigator to closely monitor animal activity and behavior.

PRIMARY REQUIREMENTS (CONT'D)

STATUS

| | |
|---|---|
| • 20 channels required for specimen data collection | M |
| • Waste collection system shall allow daily collection of solid waste | P |
| • Color, black and white, and infrared video monitoring is to be available at all times | M |
| • Habitat shall be designed to allow for unpowered visual observation of the animal | M |

*Status legend: M=Met P=Partially met N= Not met U=Unknown

BACK OF PRIMARY REQUIREMENTS CHART

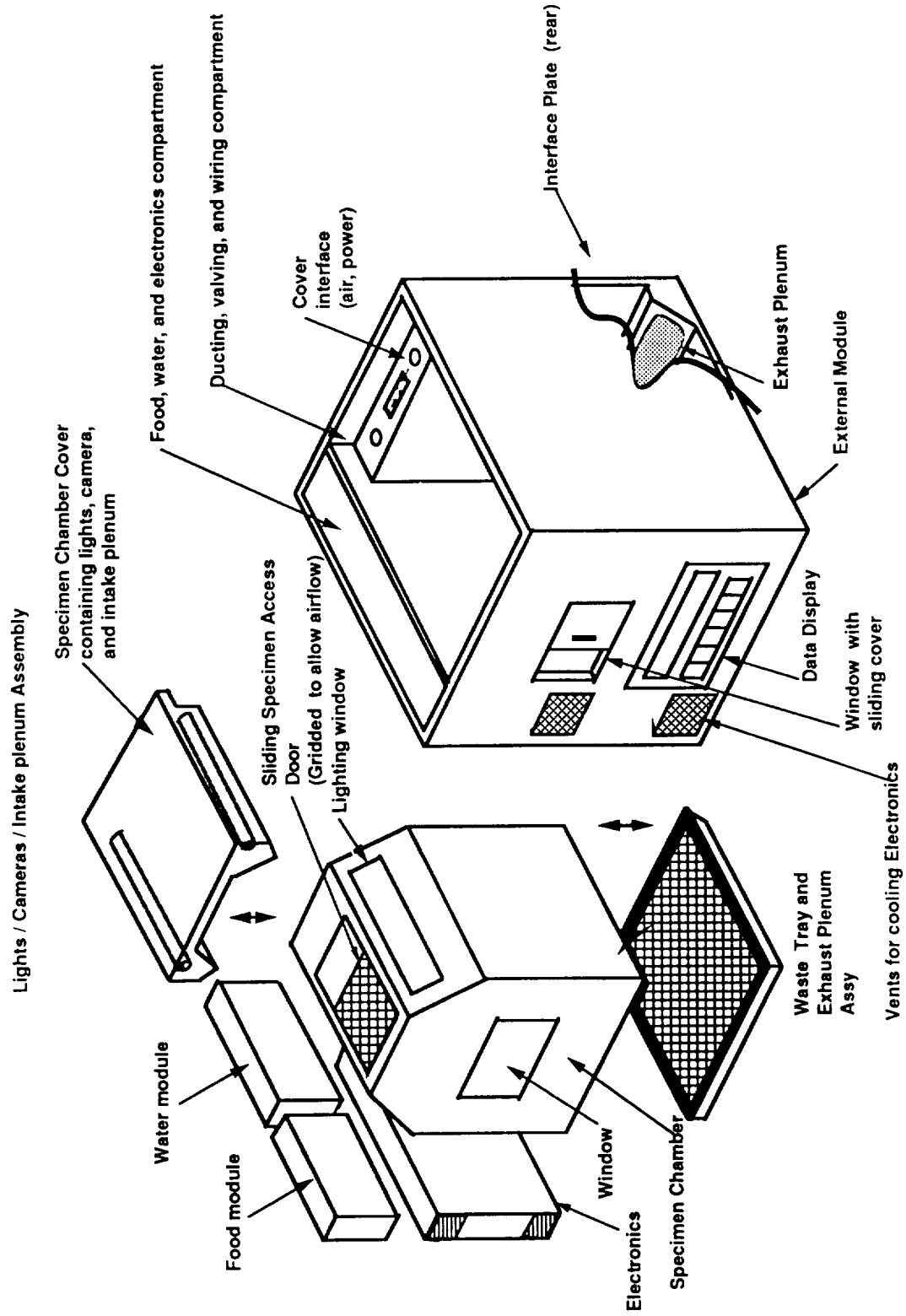
UNRESTRAINED SQUIRREL MONKEY HABITAT

DESIGN DESCRIPTION

The exploded isometric view on the facing page illustrates the habitat's modular components including the specimen chamber, specimen chamber cover assembly, waste tray assembly, food module, water module, electronics modules, and external module. The approximate locations of the rest of the habitat's hardware (e.g., data display, inlet and exhaust plenums, etc.) are also shown.

Orthographic views of the habitat are provided in the appendix at the end of this chapter of the report to illustrate some of the design details.

EXPLODED VIEW



DESIGN DESCRIPTION (CONT'D)

The Unrestrained Squirrel Monkey Habitat has external dimensions of 43cm wide x 51cm deep x 61cm high (17" x 20" x 24"). This envelope is chosen to meet the science requirements and to optimize the Holding System storage capacity (i.e., two Rodent Habitats fit in the same volume as the Unrestrained Squirrel Monkey Habitat).

The specimen chamber is 47cm (18.5") tall at its peak and has a floor area of 1,350 cm² (210 in²) : 34.3 cm wide x 40.6 cm deep (13.5" x 16"). The specimen chamber top is chamfered to provide the required standing height and to accommodate the fluorescent lighting fixtures. In its basic configuration, the specimen chamber, the cover assembly, and the waste tray assembly are assembled as one unit to provide the primary layer of bio-isolation around the specimen.

The waste tray is removed with the specimen chamber through the top door of the habitat. A grid floor over the waste tray has holes large enough to allow all waste materials to pass through to the collection area. It is elevated about 2 cm (1") above the absorptive materials in the waste tray to prevent the squirrel monkey from reaching into the tray. The absorptive materials are chemically treated to prevent odors and act as a coarse filter for the outgoing air.

Lights and electronics are cooled by a separate cabin air stream from the ECLS air. The ECLS air is preconditioned prior to entering the habitat; a heater and humidifier in the habitat is for final adjustments in temperature and humidity control.

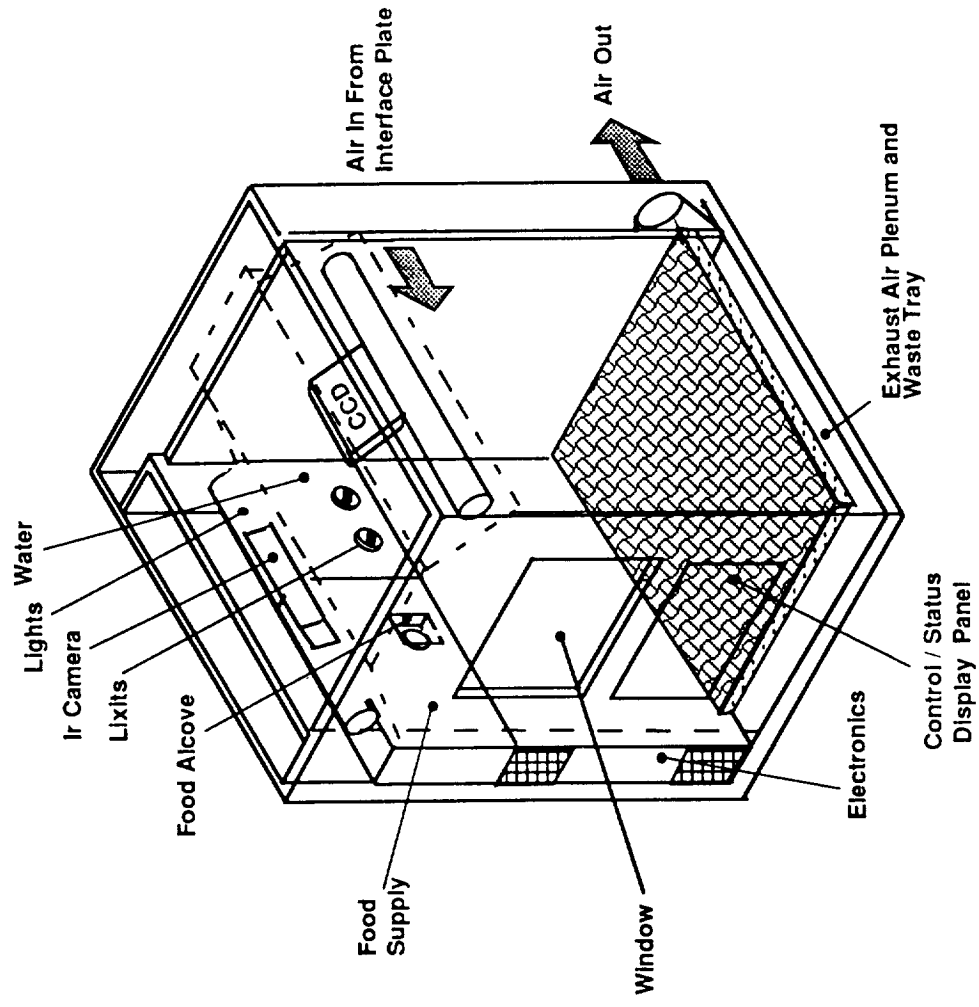
UNRESTRAINED SQUIRREL MONKEY HABITAT

- 60,600 cm³ (3,700 in³) specimen chamber volume, 1,350 cm² (210 in²) floor area
- Pent-roof design allows 47 cm (18.5") standing height within specimen chamber
- 1.5 liter water reservoir, automatically replenished through system interface
- 14 day supply of food, tap-switch activated delivery
- Waste tray removed with the specimen chamber through top door of habitat
- Electronics, food, and water module are accessible through the side of the habitat
- Lights and electronics are cooled by circulating cabin air
- Color, black and white, and IR video along with direct visual observation
- Single pass air flow, conditioned at inlet
- Heater and humidifier for temperature and humidity control

DESIGN DESCRIPTION (CONT'D)

An isometric view of the Unrestrained Squirrel Monkey Habitat is shown on the facing page. Shown are the approximate locations and configuration of the habitat's hardware including: the waste tray, light fixtures, electronics module, food module, water module, the water lixits, food alcove, and ECLSS air inlet and outlet.

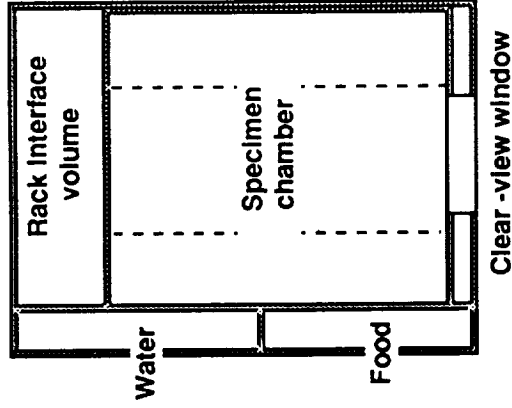
ISOMETRIC VIEW



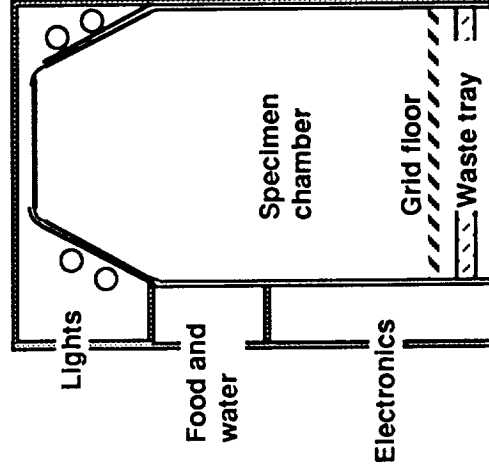
DESIGN DESCRIPTION (CONT'D)

Sketches of the habitat top and front view, complementing the isometric view, are shown on the facing page.

PLAN VIEW



Top Plan View



Front Elevation View

DESIGN DESCRIPTION (CONT'D)

The block diagram for the Unrestrained Squirrel Monkey Habitat is shown on the facing page. This diagram illustrates the flow of cabin air, ECLSS air, and water. The cabin air loop removes the heat produced by the lighting and electronics modules.*.

The ECLSS air flow is shown by the lightly shaded line. HEPA filters are installed at the inlet and exhaust of the ECLSS loop to provide one level of bioisolation for the respiration air flow. The habitat operates under negative pressure relative to the cabin to provide a second level of bioisolation.

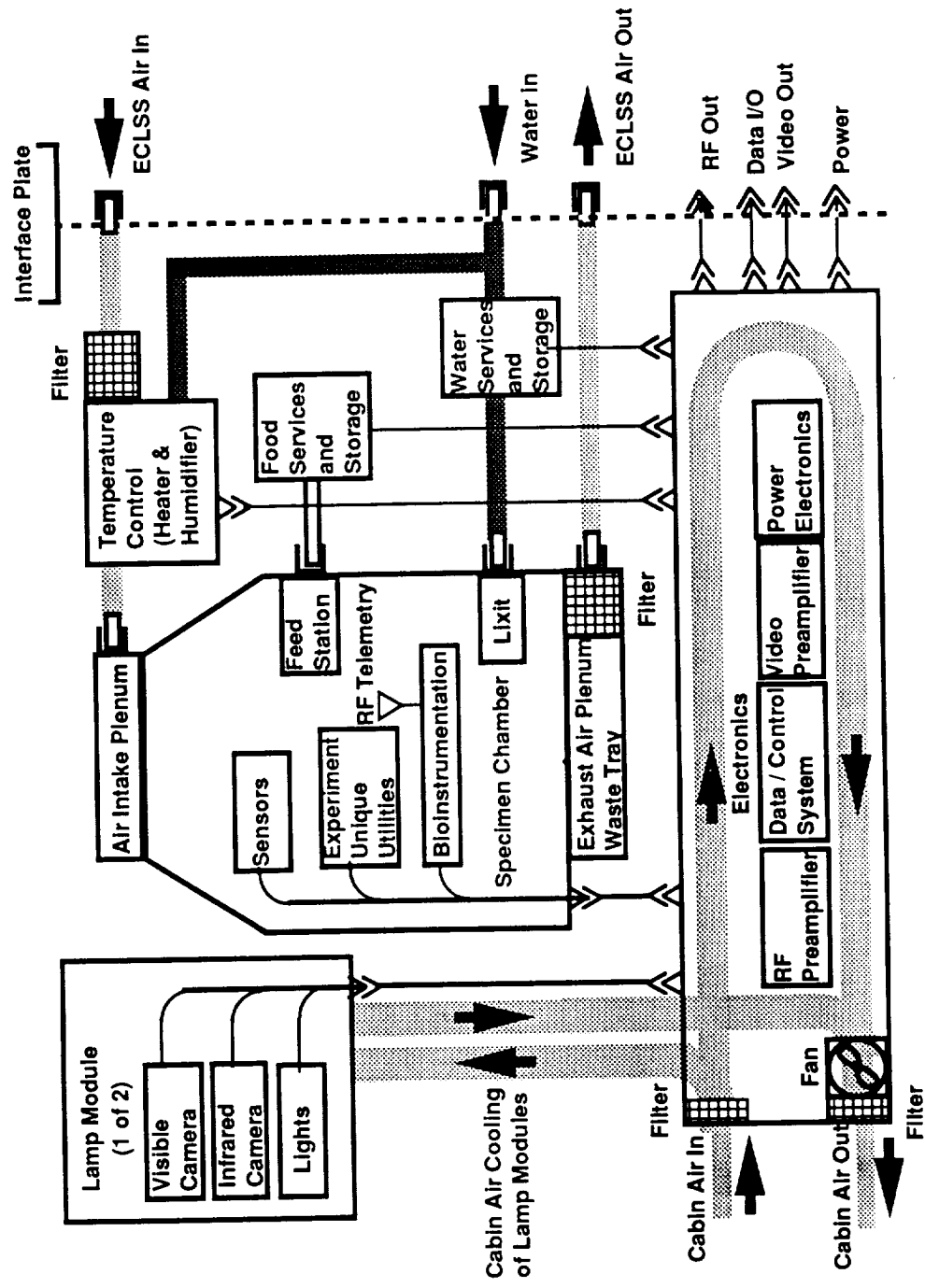
The specimen chamber humidity and temperature are controlled to the desired set-points at the habitat level using a heater and humidifier.

A 14 day food supply is provided in the habitat with a tap switch feeder for behavioral enrichment. It can be programmed for a variable or ad libitum delivery schedule as desired by the investigator. A 1.5 liter water reservoir supplies the habitat with a full day's water supply plus contingency. The reservoir is replenished daily from a main reservoir in the Holding Unit or Centrifuge. The diagram also depicts where quick-disconnects are required in the habitat.

* Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore, this feature of the design will have to be modified.

BLOCK DIAGRAM

UNRESTRAINED SQUIRREL MONKEY HABITAT BLOCK DIAGRAM

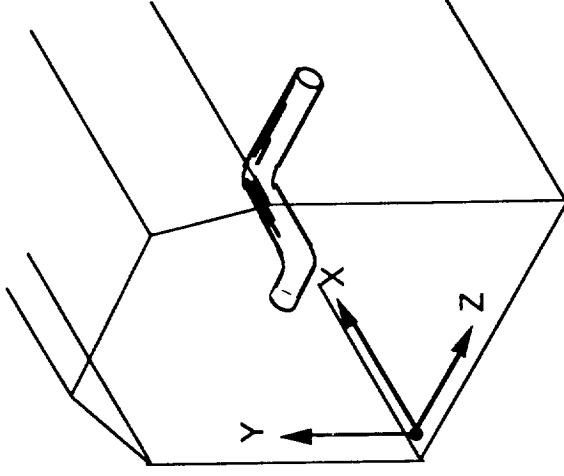


DESIGN DESCRIPTION (CONT'D)

A perch is required in the Unrestrained Squirrel Monkey Habitat as an aid to promote normal animal behavior and to prevent foot sores caused by prolonged standing on a cage floor. The sketch on the facing page shows the selected design which allows the Squirrel Monkey to grasp the perch in any orientation in space.

Numerous perch designs considered in this study are described in the appendix to this chapter.

PERCH DESIGN



Squirrel Monkey Perch

- Perch is 2 cm (3/4") diameter
- Perch is useable in all three axes in micro-gravity
- Minimal chamber volume penalty

TRADEOFFS

A list of the tradeoffs performed in the design of the Unrestrained Squirrel Monkey Habitat is presented on the facing page.

TRADEOFFS

- Specimen handling technique
- Specimen chamber configuration

TRADEOFFS (CONT'D)

SPECIMEN HANDLING TECHNIQUE

Specimen handling may be difficult in the Unrestrained Squirrel Monkey Habitat. This is due to the limited reach and limited visibility into the habitat from the Glovebox. A tradeoff between handling techniques and hardware designs was performed to compare methods of capture which had minimal impact on the habitat design and operator handling.

The "pole and collar" handling technique was chosen over other methods. In this method, the monkey is fitted with a collar to which a pole could latch. This gives the handler added reach and ability to guide the monkey in the desired direction. The pole and collar technique offers the handler the option of using gloves should he feel comfortable enough with his skills in working with the animal, thus reducing the required crew time. This particular technique is used by the animal handlers in the ARC animal care facility.

The facing page summarizes the options considered in this tradeoff and highlights the pros and cons associated with the various handling techniques. Note that the '+' and '-' symbols are qualitative and are not to be tallied to determine the quantitative merits of each option.

TRADEOFFS (CONT'D)

SPECIMEN HANDLING TECHNIQUES

| Squeeze Wall | Net Techniques | Food Cage System | Pole and Collar | Gloved Hand |
|---|--|--|--|--|
| Movable wall forces monkey to a controlled space | A unique 0-g net captures the monkey | Food within a removable cage lures monkey | Monkey has ringed collar to which pole or leash attach | Astronaut wears a protective glove to handle monkey |
| <ul style="list-style-type: none"> + Commonly used in the laboratory + Could be operated manually - System effects perch and feeder designs - Reduces specimen chamber size - Moving wall will be difficult to clean - Sliding mechanisms may injure animal | <ul style="list-style-type: none"> - Must develop 0-g net mechanism - Operator training required + Independent of perch and feeder design + Little effect on specimen chamber - Net may be difficult to clean - Tangled animal may injure itself | <ul style="list-style-type: none"> - Not commonly used in laboratory + Little training required - System effects perch and feeder designs - Reduces specimen chamber size - Cage may be difficult to clean - Dependent on feeding schedule | <ul style="list-style-type: none"> + Commonly used in the laboratory - Operator training required + Independent of perch and feeder design - Astronaut must reach within chamber + Easy to clean - Monkey must be visible to astronaut | <ul style="list-style-type: none"> + Commonly used in the laboratory - Operator training required + Independent of perch and feeder design - Astronaut must reach within chamber + Easy to clean - Monkey must be visible to astronaut |

Current choice: The pole and collar technique is chosen over the gloved hand method because of difficulty reaching into the specimen chamber (20" depth) at the Glovebox and limited view of the squirrel monkey.

TRADEOFFS (CONT'D)

SPECIMEN CHAMBER CONFIGURATION

The overall habitat envelope and the requirement to locate the light fixtures in the top one-third of the specimen chamber require a specially designed habitat to meet the specimen chamber vertical height requirement. Moreover, operations and other functional requirements such as serviceability, and volume efficiency must be considered for the habitat design.

Three specimen chamber configurations were considered in a tradeoff study to determine the most suitable chamber configuration to meet the mentioned requirements. The chamfered-roof configuration best satisfied the above criteria because:

- 1) It satisfies the minimum standing height and the lighting location requirements
- 2) It is the best hardware packaging design with the least impact on the monkey's living space
- 3) Its modular design (i.e., lighting fixtures are parts of the cover assembly) improves accessibility.

The facing page summarizes the options considered in this tradeoff and highlights the pros and cons associated with various Specimen Chamber configurations. Note that the '+' and '-' symbols are qualitative and not to be tallied to determine the quantitative merits of each option.

TRADEOFFS (CONT'D)

SPECIMEN CHAMBER CONFIGURATION

| Top-mounted Lighting | Side-mounted Lighting | Chamfered-roof Specimen Chamber |
|---|--|---|
| Rectangular specimen chamber with lights at top of chamber - Only 30% of top surface available for access door + Compatible with squeeze-wall designs + Simplifies chamber illumination - Lamp modules may have to be removed for specimen access - Does not meet standing height requirements | Rectangular specimen chamber with lights at side of chamber + 80% of top surface available for access door + Compatible with squeeze-wall designs + Large volume available for intake plenum + Lamp module would not have to be removed for specimen access - Increases chamber wall complexity | Rectangular specimen chamber with top corners chamfered - Only 50% of top surface available for access door - Restricts movement in squeeze-wall designs - Reduced volume available for lamp modules + Lamp module would not have to be removed for specimen access + Meets standing height requirements |

Current Choice: A chamfered-roof specimen chamber makes it possible to meet the squirrel monkey standing height requirements and uses a compact lighting module.

OPERATIONS ISSUES SUMMARY

Operations, logistics, and stowage affect the ability to comply with the science experiments. These functions must be considered in the habitat design to reduce necessary service operations and crew time.

Further examination of reusable vs. disposable specimen chambers is required to determine the impacts on stowage and other resources. Moreover, detailed operation scenarios and typical science protocols are needed to check the feasibility of the design concepts presented.

An outline of the operations issues considered in the design process is listed on the facing page.

OPERATIONS ISSUES SUMMARY

- Habitat designs should reduce dependence on Glovebox
- Disposable features may reduce crew time for operations at the Glovebox
- Unrestrained animal handling will require crew training
- A clean empty habitat must be available at all times for servicing

Back of Operations Summary Chart

DATE: 6/26/90

CENTRIFUGE FACILITY SYSTEM STUDY

CHAPTER 3 . PAGE 32

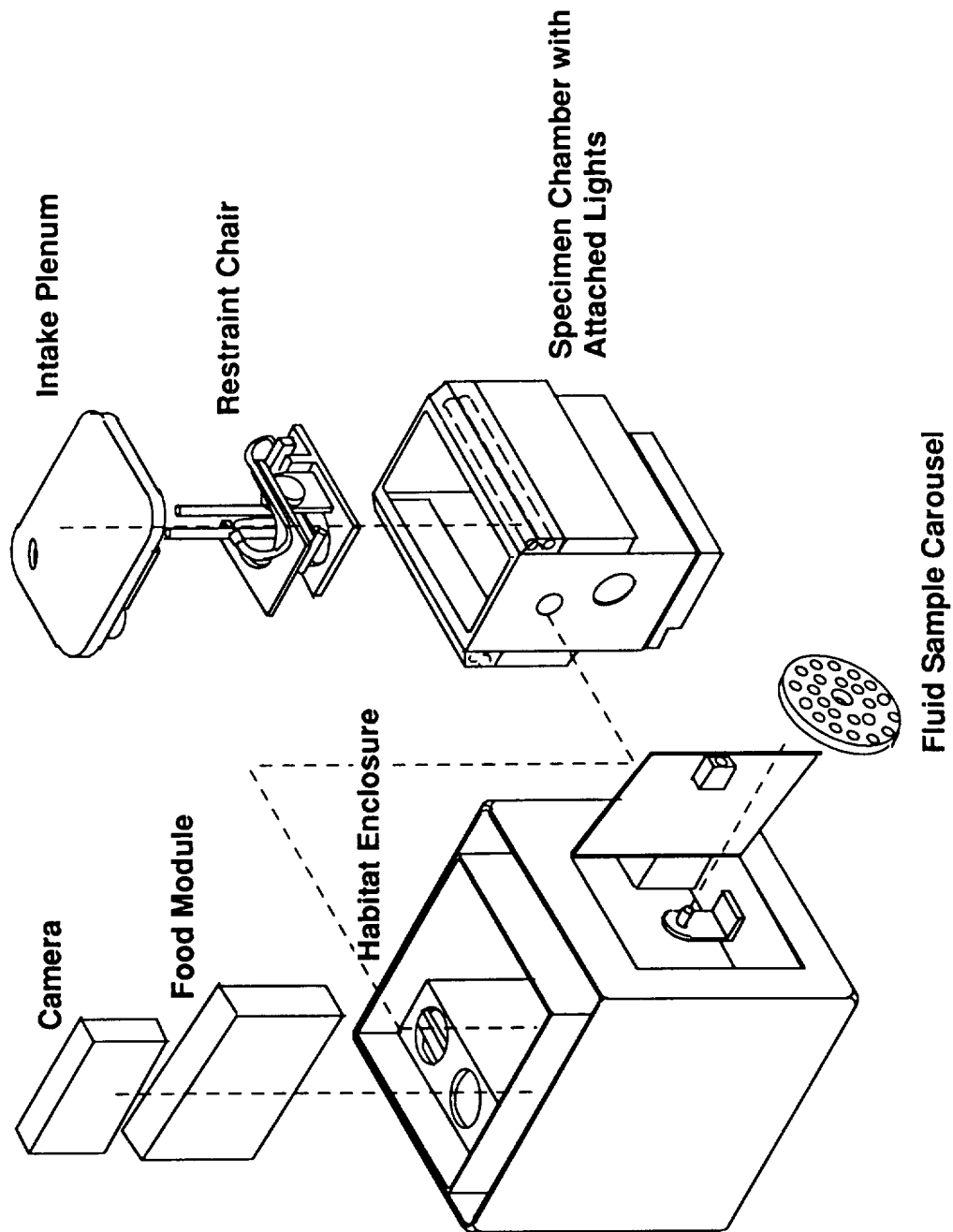
RESTRAINED SQUIRREL MONKEY HABITAT

DESIGN DESCRIPTION

The isometric view on the facing page illustrates the major components of the Restrained Squirrel Monkey Habitat. Modularity of each major component simplifies service operations.

EXPLODED VIEW

Restrained Squirrel Monkey Habitat



DESIGN DESCRIPTION (CONT'D)

The use of a restrained squirrel monkey is required for some science disciplines. Protocols will require experimental data collection, body fluid samples (e.g., blood and urine) and experiment unique measurements. The restraint system prevents the squirrel monkey from disconnecting the sample collecting systems and must be designed to restrain the animal for up to 2 weeks without causing stress or injury. The restraint system design will complicate some subsystem designs, i.e., the feeder and lixit designs, and simplify others, i.e., the waste management system.

The external dimensions for the Restrained Squirrel Monkey Habitat are 43cm wide x 51cm deep x 48cm high (17" x 20" x 19"). The habitat accommodates a 33 cm wide x 20 cm deep x 33 cm high (13" x 8" x 13")* specimen chamber and other modular components including: food, water, camera, electronics. The restraint design and the fluid sampling system are similar to the RAHF squirrel monkey habitat designs. The restraint chair is removeable and differs from the RAHF chair in that it allows the animal to be restrained in two orthogonal orientations. This is in compliance with the science requirements to be able to hold the monkey on the Centrifuge with the gravity vector in either the front-to-back or head-to-toe orientations. In the Restrained Squirrel Monkey Habitat, the animal's urine can be removed via a catheter and stored on the fluid sample carousel. The fluid sample carousel is designed to provide storage for fluid samples (@ 50 ml/sample), which are accessible through the front of the habitat. There are a total of five fluids lines in the Restrained Squirrel Monkey Habitat; one is reserved for potable water delivery to the lixit attached to the chair, one for urine collection as mentioned, and three to be used for variable experiment objectives. Finally, the habitat provides video monitoring capability in color, black and white, and infrared (for the dark cycle), and has windows for direct visual observation of the specimen.

* Recent information indicates that the restrained squirrel monkey will require more height so the design will have to be modified to reflect this.

RESTRAINED SQUIRREL MONKEY HABITAT

- Habitat size 43cm wide x 51cm deep x 48cm high (17" x 20" x 19")
- Specimen chamber size 33 cm wide x 20 cm deep x 33 cm high (13"x 8"x 13")
- Specimen access through top of habitat
- Restraint and fluid sampling designs similar to RAHF
- Front panel display of status and function controls
- Specimen chamber and lights separated from other habitat systems by a wall
- HEPA filters at inlet and exhaust of the specimen chamber provide barriers to microbial contamination; replaced from the top of the habitat
- Water delivered to specimen through fluid coupling on restraint chair
- Specimen is handled using removable restraint chair
- Restraint chair accommodates two specimen orientations; orientations are orthogonal
- Three of five fluid sample lines are available to the experimenter
- Fluid sample storage carousel provides up to 64, 10 ml samples
- RF antenna integrated into specimen restraint jacket
- Color, black and white, and IR video is provided
- Window provided for direct visual observation

DESIGN DESCRIPTION (CONT'D)

Similar to the Unrestrained Squirrel Monkey Habitat, the Restrained Squirrel Monkey Habitat system has a passive waste management system which uses air to transport waste to a waste tray lined with absorptive materials. The collected waste matter in the Restrained Squirrel Monkey Habitat is prevented from reentering the specimen chamber by a waste tray cover.

The urine from the restrained squirrel monkey is removed using a catheter and is stored in a fluid sample carousel. This carousel is accessible from the front of the habitat.

The unique functional and volumetric constraints of the Restrained Squirrel Monkey Habitat both facilitate and hinder waste collection. Because the specimen is immobilized, waste collection can be localized within the specimen chamber. However, because the specimen chamber is smaller, less volume is available for a waste collection system.

RESTRAINED SQUIRREL MONKEY HABITAT

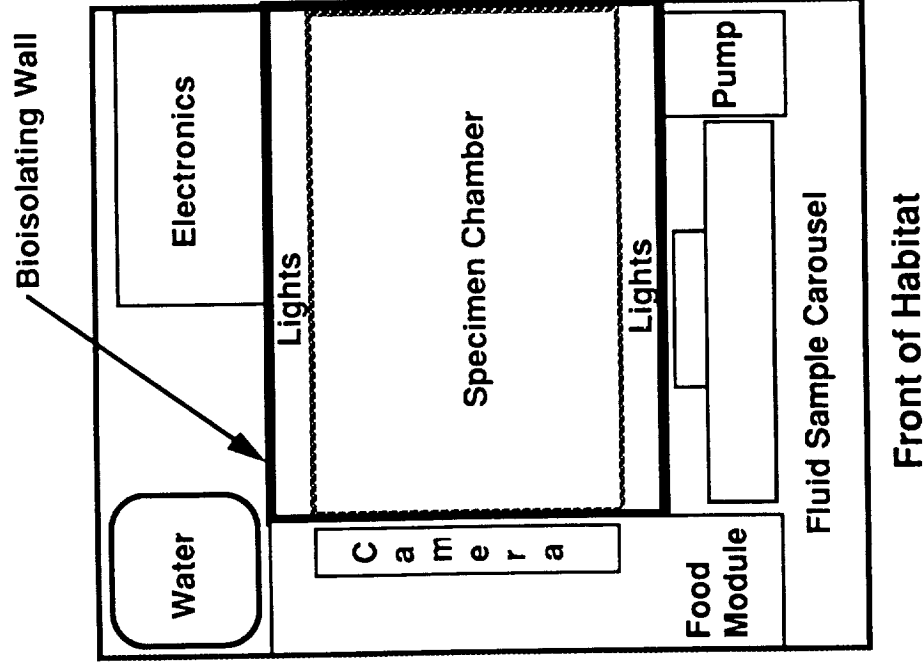
- Replaceable waste collection absorptive filter in the waste receptacle
- Urine removed using catheter and stored in fluid sample carousel
- Fluid samples can be accessed through the front of the habitat
- Solid waste management system permits the collection of samples

DESIGN DESCRIPTION (CONT'D)

The top view of the Restrained Squirrel Monkey Habitat on the facing page illustrates the relative locations of the modular housekeeping components inside the habitat. With the exception of the fluid sample carousel, which is accessible from the front of the habitat, the rest of these components are accessible from the top.

TOP VIEW

RESTRAINED MONKEY HABITAT TOP VIEW

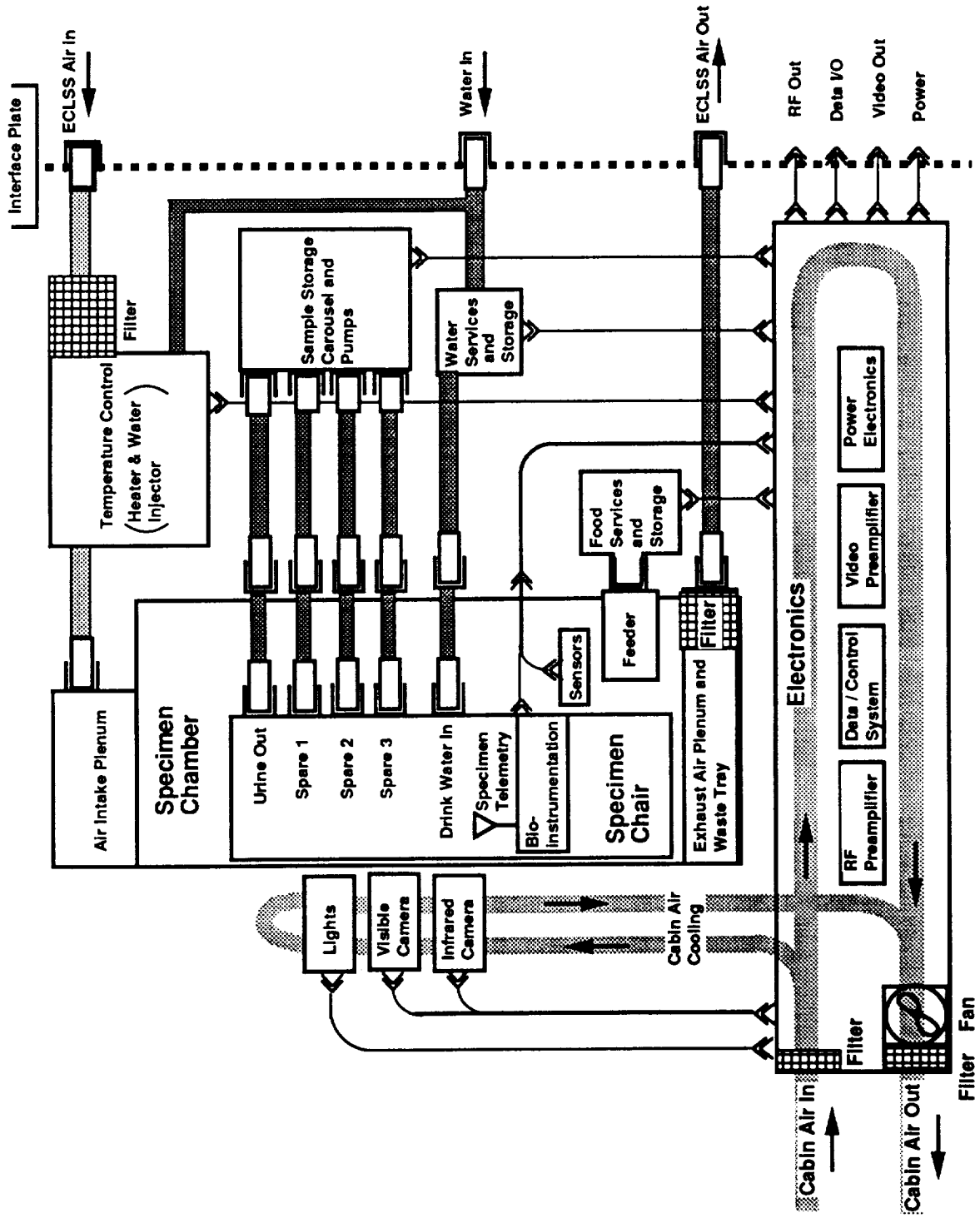


BLOCK DIAGRAM

The block diagram on the facing page shows the ECLSS air loop, the electronics air loop, all the fluid lines, and the interconnections between the habitat components. HEPA filters are installed at the air inlets and exhausts, and cabin air is used in cooling the electronics, lights, and cameras.* In order to avoid contamination of components within the habitat, separate air sources for the specimen chamber ECLSS and cooling for electronic components were used.

* Recent information from the Freedom Program indicates that severe constraints have been placed on cabin air heat loads. Therefore, this feature of the design will have to be modified.

BLOCK DIAGRAM RESTRAINED SQUIRREL MONKEY HABITAT



DESIGN DESCRIPTION (CONT'D)

As mentioned earlier, the restraint chair design is a modification to the restraint chair designed for RAHF. The RAHF chair has been demonstrated to be biocompatible with squirrel monkeys and is scheduled for a shuttle flight experiment SLS-2. A sketch of the restraint chair is shown in the Appendix to this chapter of the report.

A design goal was to provide a restraint chair which is easily reoriented and provides an easy means of sample collection. The chair designed in the study is removable. This approach results in easy animal handling, allows implanted fluid apparatus (i.e., catheters and needles) to remain with the animal when it is removed from the specimen chamber, helps to prevent injuring the animals and should require less crew time than other designs.

While the dual-orientation design reduces the stowage required (one chair vs. two) and reduces the set-up operations, it complicates the design in other areas. For example, feeder and water ligit location and routing for fluid sampling lines are complicated because they must function in both chair positions. Further design considerations would include provision for mobile video observation (frontal view) and solid waste collection.

The current fluid sampling system design is a modification to that used in the RAHF program. This system was designed to collect samples of the monkey's urine at variable intervals. A pump and reservoir, accessible from the front of the habitat, are used in collecting and subsequently emptying the specimen's urine at indexing time into storage vials in the sampling carousel. A sketch of the fluid sampling system and its fluid connections is illustrated in the Appendix.

RESTRAINT CHAIR

- One chair to accommodate both specimen orientations
- Removable (from the habitat) chair increases specimen safety: easy to handle
- RAHF chair design safe for the specimen; not tested in zero gravity
- Water feed to the chair eliminates hardware within the specimen chamber
- Catheter could remove urine (male monkeys) to store in fluid sampling carousel; reduces liquid waste in specimen chamber
- Collect solid waste and urine (non-catheterized monkeys) in RAHF style waste tray
- Five fluid lines from chair; limited by disconnect size and fluid specimen sampling needs

TRADEOFFS

Two restraint chair configurations were considered in the study. The dual-position chair was selected over the single position design for the reasons shown on the following page.

RESTRAINT CHAIR CONFIGURABILITY

The restraint chair must accommodate two specimen orientations

| Dual-Position Restraint Chair | Single-Position Restraint Chair |
|--|--|
| <ul style="list-style-type: none"> + Single chair accommodates both specimen orientations - Fluid lines and hardwired animal telemetry must be flexible + Restraint chair can be reoriented with little disturbance to specimen - Complex design - Waste management system must accommodate flexible specimen orientation | <ul style="list-style-type: none"> + Separate chairs for each specimen orientation simplifies each chair design + Fluid lines need not be flexible - Specimen reorientation will be difficult - Requires two chair designs |

Current Choice: Concerns for specimen safety during reorientation and reduction of hardware favor a dual-position chair

TRADEOFFS (CONT'D)

Placement of the water lixit in the Restrained Squirrel Monkey Habitat is critical since it must be accessible to the restrained animal in both orientations. Three alternatives were investigated. The most viable alternative was to locate the lixit on the specimen chair. This approach reduced the specimen chamber complexity by reducing the plumbing behind the chamber walls.

WATER LIXIT PLACEMENT

Water must be provided to the restrained monkey in both orientations

| Lixit located on specimen chair | Fixed lixits on chamber wall | Moveable lixit on chamber wall |
|--|---|---|
| <ul style="list-style-type: none"> - Adds complexity to restraint chair + Reduces plumbing inside the habitat + Simplifies specimen operations - Flexible joint for water delivery | <ul style="list-style-type: none"> + Simplifies restraint chair + Fewer disconnects required - Two lixits required | <ul style="list-style-type: none"> + Simplifies restraint chair + Fewer disconnects required - Burdens specimen operations - Requires reorientation for alternate restraint chair configuration |

Current choice: With the lixit located on the specimen chair, plumbing inside the habitat and reorientation are simplified.

OPERATIONS ISSUES SUMMARY

Many of the operations issues for the Unrestrained Squirrel Monkey Habitat apply as well to the Restrained Squirrel Monkey Habitat. Operations issues which are unique for the Restrained Squirrel Monkey Habitat are shown on the facing page. These issues involve fluid sampling or reorientation of the specimen during centrifuge usage. As mentioned before, efforts have been made in the design to reduce the crew time required for these operations.

OPERATIONS ISSUES SUMMARY

- Restraint duration will be restricted (< 15 days)
- Front access to fluid sample carousel
- Animal handling is simplified with restraint chair
- Reorientation of the animal by 90°

Back of Operations Issues Summary

DATE: 6/26/90

CENTRIFUGE FACILITY SYSTEM STUDY

CHAPTER 3 . PAGE 52

COMMON ELEMENTS FOR RESTRAINED AND UNRESTRAINED SQUIRREL MONKEY HABITAT

COMMON DESIGN FEATURES

To reduce program costs and complexity, efforts were made to incorporate common design features in both the Restrained and Unrestrained Squirrel Monkey Habitats. The two habitats share design features in the following areas: food delivery system, lighting technology, electronics modules, and ECLS system.

The feeders and water licks in both habitats are similar, the only difference being additional hardware for the Restrained Squirrel Monkey Habitat feeder mounting arrangements.

Both habitats use fluorescent lights, but due to a larger floor size to be illuminated in the Unrestrained Squirrel Monkey Habitat, a larger lighting unit is required.

The electronics modules in both habitats use similar system architecture and interfaces, and must meet similar requirements. The most notable functional differences between the two habitats are the fluid sample scheduling and the sample carousel control required for the Restrained Squirrel Monkey Habitat.

COMMON DESIGN FEATURES

Food/water

- Similar food storage containers
- Delivery mechanisms may have similar components
- Similar water delivery systems

Lighting

- Similar technology and hardware components

Electronics

- Similar sensors and connectors

DESIGN DESCRIPTION

Although the feeder system designs are similar for unrestrained and restrained squirrel monkeys, the design for the restrained squirrel monkey presents unique design challenges. The most difficult requirement is to design a feeder capable of providing food which is accessible to the restrained squirrel monkey in two orientations. Additional studies are necessary to determine:

- 1) The optimum location for the feeder
- 2) Unique characteristics of the Restrained Squirrel Monkey Habitat feeder

MONKEY FEEDER

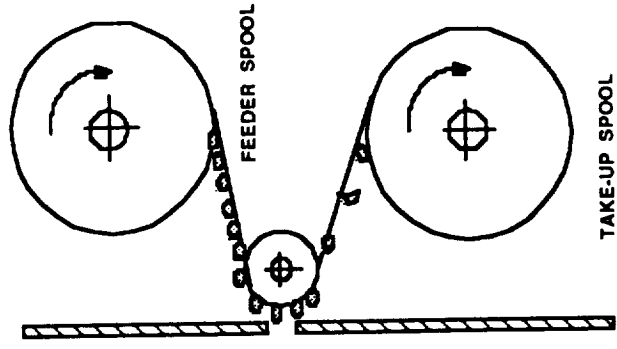
Restrained Squirrel Monkey Feeder

- Feeder must be capable of delivery in both specimen orientations
- Feeder tap switch must be capable of actuation by the monkey in both orientations
- Feeder must be insensitive to the effects of gravity in operation (ground control and on Centrifuge)
- Flexible delivery point requires controlled placement of the food pellet within the specimen chamber
- Baseline "tape" feeder separates food pellets and simplifies pellet acquisition

DESIGN DESCRIPTION

The sketch on the facing page depicts the functional aspect of the tape feeder. In principle, the feeder uses a feed and a take-up spool to advance food pellets that are individually encapsulated on a roll of foil tape. Subsequently, the encapsulated casing is broken by a plunger and the pellets are presented to the monkey through the food alcove opening.

TAPE FEEDER ILLUSTRATED



ELECTRONICS FUNCTIONS

A list of the habitats electronics functions is shown on the facing page.

ELECTRONICS FUNCTIONS

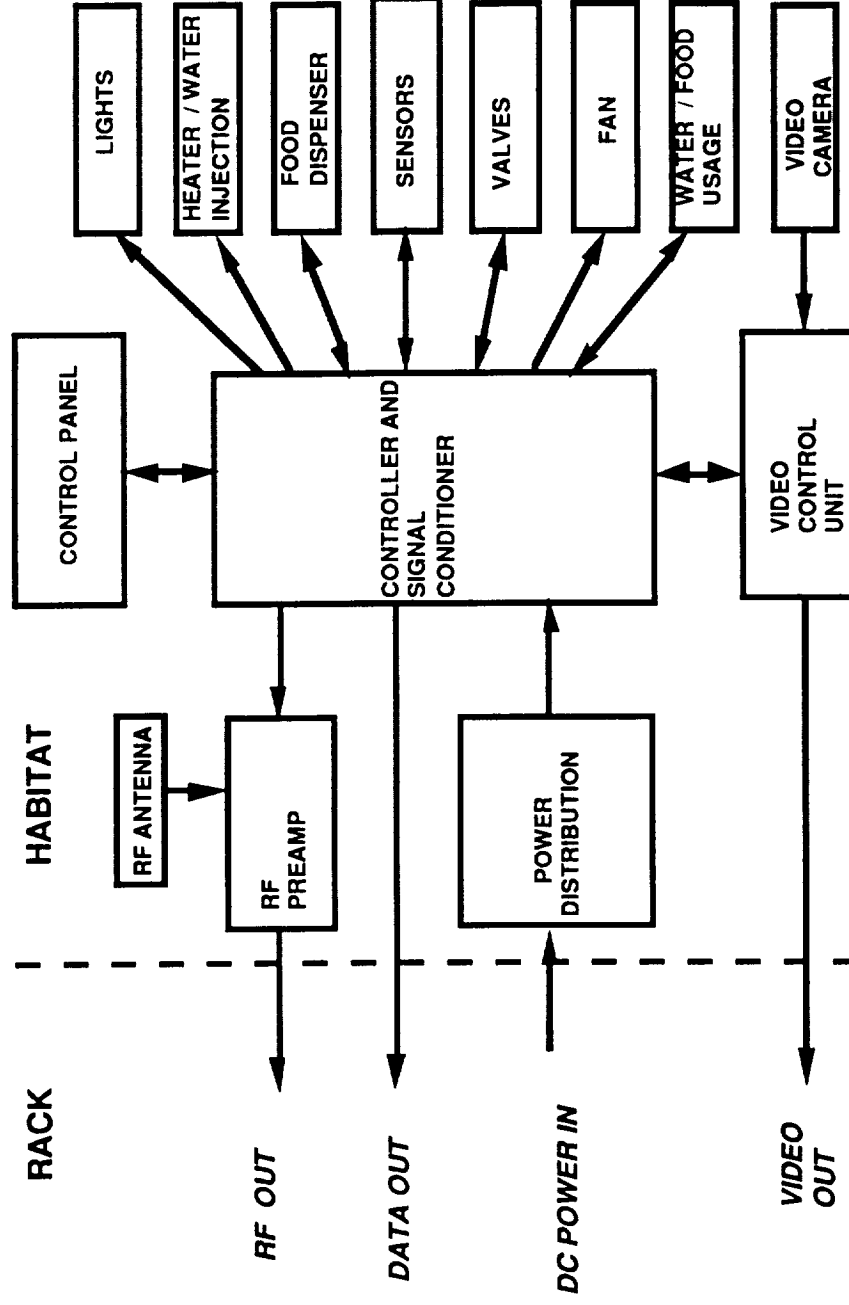
- Food usage monitoring and dispensing control
- Water usage monitoring
- Specimen chamber environmental control: temperature and humidity
- Waste management system status: airflow, urine output, and filter condition
- Fluid sample scheduling and sample carousel control
- Processing of monkey physiological data from RF or hardwired sensors
- Lighting intensity control and period
- Video switching and data processing
- Front panel display and request processing
- Power distribution and conditioning within the habitat
- Contamination monitoring

ELECTRONICS BLOCK DIAGRAM

A block diagram representing the electronic architecture and rack interfaces for both Squirrel Monkey Habitats is shown on the following page. The Restrained Habitat electronics block diagram would include additional blocks for fluid sampling and carousel control.

ELECTRONICS BLOCK DIAGRAM

ELECTRONICS BLOCK DIAGRAM



HABITAT CHARACTERISTICS

This chart represents the current mass estimates for the Restrained and Unrestrained Squirrel Monkey Habitats. The individual component estimates are based on engineering judgment, catalogue values, and calculations (abbreviated under the Basis column as Rough, Cat, or Calc, respectively). A 25% mass contingency was added to the respective totals to account for uncertainties made in these estimates. The worst-case estimates shown here, 61 kg (135 lbs) and 73 kg (160 lbs) for the Restrained and Unrestrained Squirrel Monkey Habitats respectively, may present handling problems. This is of great concern and should be addressed in future habitat designs.

HABITAT CHARACTERISTICS

Habitat Mass Estimates

| Subsystem and Components | | | | | |
|-------------------------------------|----------|---------------|----------|---------------|------|
| Structure (.090" Al) | 11 (24) | 133.7 (8,160) | 8 (18) | 106.0 (6,469) | Calc |
| Specimen chamber (.040" SS) | 4 (8) | 60.6 (3,700) | 2 (5) | 22.3 (1,360) | Calc |
| Insulation (80 lbs/cu ft) | 7 (15) | 5.7 (348) | 5 (10) | 4.1 (250) | Calc |
| Interface Plate | 5 (10) | 4.9 (300) | 5 (10) | 4.9 (300) | Calc |
| Electronics | | | | | |
| Front Control Panel | 1 (2) | 0.7 (40) | 1 (2) | 0.7 (40) | Calc |
| Module | 5 (10) | 4.5 (275) | 5 (10) | 4.5 (275) | Calc |
| Wire | 5 (10) | 1.6 (100) | 4 (8) | 1.3 (80) | Calc |
| Sensors | 2 (5) | 1.6 (100) | 2 (5) | 1.6 (100) | Calc |
| Fan | 1 (2) | 0.3 (20) | 1 (2) | 0.3 (20) | Calc |
| Subsystems | | | | | |
| Water Module | 2 (5) | 1.8 (110) | 2 (4) | 1.1 (70) | Calc |
| 2 Lamp Modules | 5 (10) | 3.1 (190) | 5 (10) | 3.1 (190) | Calc |
| Cameras | 1 (2) | 0.7 (40) | 1 (2) | 0.7 (40) | Calc |
| Intake Plenum | 5 (10) | 10.3 (630) | 3 (6) | 6.1 (370) | Calc |
| Exhaust Plenum | 7 (15) | 16.9 (1,030) | 3 (6) | 8.2 (500) | Calc |
| Fluid Sample Carousel | NA | NA | 5 (10) | 13.1 (800) | Calc |
| Total | 58 (128) | 247* (6,885) | 49 (108) | 178 (4,395)* | |
| Total Mass + 25% Design Contingency | 73 (160) | | 61 (135) | | |
| Utilization of available volume: | | 85% | | 70% | |

* These totals do not include the enclosure volume

HABITAT CHARACTERISTICS (CONT'D)

Nominal and peak power estimates for the Squirrel Monkey Habitats are presented on the following chart. These estimates are based on engineering judgment, catalogue values, and calculations (as aforementioned). As shown, lighting is projected as the single largest power consumer in the habitats. These power estimates do not include a contingency.

HABITAT CHARACTERISTICS (CONT'D)

Habitat Power Estimates

| Subsystem and Components | Power in Watts | | | | Basis |
|--------------------------|----------------|------|------------|------|-------------|
| | Unrestrained | | Restrained | | |
| | Nominal | Peak | Nominal | Peak | |
| Light | 30 | 80 | 20 | 60 | Calc |
| Food Module | 1 | 15 | 1 | 15 | Rough |
| Pumps | NA | NA | 0 | 15 | Cat |
| Electronics Module | 5 | 10 | 5 | 10 | Rough |
| Front Control Panel | 1 | 10 | 1 | 10 | Cat |
| Water Module | 1 | 10 | 1 | 10 | Rough |
| Sensors | 1 | 10 | 1 | 10 | Rough & Cat |
| Heater | 1 | 10 | 1 | 10 | Calc |
| Fan | 10 | 10 | 10 | 10 | Cat |
| Camera | 5 | 5 | 5 | 5 | Cat |
| Total | 55 | 160 | 45 | 155 | |

Maximum estimated thermal load to cabin air: 120 Watts

TRADEOFFS

FEEDER

Two basic food forms (pellets and bars) were initially considered as options to feed the monkeys. However, pellets are specified by the science requirements and are used in this study. The basic science requirements on the feeder system are:

- 1) The food and delivery system shall be designed to prevent food contamination
- 2) Food dispensed from each primate dispenser shall be measured half-hourly to $\pm 1\%$ of the daily total used by each primate
- 3) The food and delivery system shall be designed to reduce food waste either by changing animal consumption patterns or by the performance of the system itself.

From these requirements, and requirements for volume efficiency and mechanical simplicity, several delivery methods were examined.

The tape dispenser is commonly used in the electronics industry, despite its relatively low storage efficiency. Since the Tape dispenser concept does not depend on contact force to advance food pellets and uses very few mechanical parts, it is not as prone to jamming and wear as other designs. Food monitoring is accomplished using an optical counter. A sketch of this tape feeder was previously shown.

The facing page summarizes the options considered in tradeoffs between feeder designs, and highlights the pros and cons associated with various feeder designs. Note that the '+' and '-' symbols are qualitative and not to be tallied to determine the quantitative merits of each option.

TRADEOFFS

Feeder Options

| Screw Type | Centrifuge Slinger | Tape Dispenser | Indexing Disk |
|---|---|--|--|
| <p>A helical wire moves loose pellets</p> <p>Frequently used in the chemical process industry and feed silo transports</p> <p>+ Relatively compact</p> <p>+ Rugged design</p> <p>+ Compatible with bulk pellet storage</p> <p>- Subject to jamming or crushing of pellets</p> <p>- Gravity required for operation</p> | <p>Centrifugal force from rotating vanes propels loose pellets</p> <p>Used in chemical process industry</p> <p>- Largest volume required for mechanism</p> <p>+ Could be used in flexible delivery system required for the restrained monkey</p> <p>+ Compatible with bulk pellet storage</p> <p>- Subject to jamming or crushing of pellets</p> <p>+ Gravity independent operation</p> | <p>Pellets are dispensed from tapes</p> <p>Some use in animal feeders, commonly used in the electronics industry for component feeders</p> <p>+ Analogs of current technology</p> <p>+ Simplified monitoring of food dispensed</p> <p>- Storage efficiency is low</p> <p>+ Reduced chances of jamming</p> <p>+ Gravity independent operation</p> | <p>A disk with pellet-sized holes traps 1 pellet and rotates to transfer the pellet to the animal</p> <p>Standard for use in laboratory primate pellet feeders</p> <p>+ Used in current laboratory feeders</p> <p>+ Compatible with bulk pellet storage</p> <p>- Some tendency to jam or crush pellets</p> <p>- Gravity required for operation</p> |

Current choice: Without further research into other designs, the tape feeder seems most certain to guarantee correct feeder operation

TRADEOFFS (CONT'D)

HEPA FILTER LOCATION

As mentioned in Chapter 1 of the report, tradeoffs between environmental control interfaces for the habitats and system hardware were performed. The outcome of one tradeoff was to provide a common air source to all habitats and a common waste port. This requires the Holding Unit and Centrifuge to use high efficiency filters in the respiration air loop to provide bioisolation between the habitats and between the Facility and Freedom.

The habitat must also be isolated during transport between Facility system locations. This must also be considered in the tradeoff studies relative to placement of filters in the habitats.

As a result of the tradeoff studies, HEPA filters were located at all air inlets and exhausts inside the Squirrel Monkey Habitats because the enhancement of bioisolation within the habitats and the reduced bioisolation on system filters outweighed the complexity added to the air plenum.

The facing page summarizes the options considered in this tradeoff and highlights the pros and cons associated with various HEPA filter locations. Note that the '+' and '-' symbols are qualitative and not to be tallied to determine the quantitative merits of each option.

TRADEOFFS (CONT'D)

HEPA FILTER LOCATION

Holding System, Centrifuge, Glovebox, and transporter have HEPA filters at inlet and outlet coupled with a Contaminant Removal System (CRS)

HEPA filters provide bioisolation (0.3 micron particle size) for the habitat

| Additional Filters Within the Habitat | Filters Provided Only Externally |
|--|---|
| <ul style="list-style-type: none"> + Enhances bioisolation within the system + Reduced stress on system filters - Filter replacement is an additional operational burden - Volume penalty within the habitat | <ul style="list-style-type: none"> + Simplified habitat design + Reduced habitat maintenance - Increased contamination in downstream ducting |

Current Choice: HEPA filters within the habitat provide additional safety in meeting bioisolation requirements.

REQUIREMENTS NOT MET

Both the Unrestrained and Restrained Squirrel Monkey Habitat designs meet most of their science and functional requirements. Requirements which were not met or require further study include the containment of collected wastes, isolation from acoustic noise, and specimen chamber floor area.

The waste collection design for the Squirrel Monkey Habitats uses airflow, as previously discussed. As the designs of the Squirrel Monkey Habitats evolve, further efforts will be devoted to developing a superior method of waste collection. Examples of technology development necessary to meet this requirement are discussed in subsequent charts.

The requirement for maintaining acoustic noise below a given value was not addressed. Therefore, the ability to meet this requirement is not known.

The current cage size is smaller than NIH recommends. Ground based studies are being performed to determine if the current cage size is adequate to provide a relatively stress-free environment for the monkeys.

REQUIREMENTS NOT MET

Unrestrained

- Specimen Chamber Design
 - Current specimen chamber floor area does not meet NIH guidelines, but meets requirements of system specifications
- Waste Collection
 - All waste is contained within the habitat; low air flow will not collect all wastes at the waste tray.
 - Collection system allows daily sampling of waste only through manipulation inside the Glovebox (requires crew; daily disturbance of animal).
 - Feces and urine are not separated

Restrained

- Waste Collection
 - Collection system allows daily sampling of solid waste only through manipulation inside the glovebox (crew intensive, daily disturbance of animal).

TECHNOLOGY DEVELOPMENT

WASTE MANAGEMENT SYSTEM

The following technological developments are required for an efficient and functional waste management system. A surface treatment technique must be developed to coat the habitat walls with a layer of durable hydrophobic material. This would help reduce the waste build-up on habitat walls. Also, an innovative design is needed to improve the waste entrainment process (i.e., improve the rate of waste particle transport to a collection location and assure waste retention). A waste tray cover must be developed to help contain the waste particles in the waste tray once they are collected. Finally, consideration must be given to disposable elements in the design.

FEEDER

Additional development is needed on a programmable feeder that satisfies the science requirements (i.e., prevents food contamination, measures dispensed food half-hourly to $\pm 1\%$, and minimizes food waste) and is volume efficient, mechanically simple, and gravity independent.

QUICK DISCONNECTS

Development of couplings which are light, dependable, and leak-free are required for quick disconnects used in all habitats.

TECHNOLOGY DEVELOPMENT

- Techniques or surface treatments which can reduce waste build-up on walls and windows within the habitat
- Waste management
- Feeders for use in zero gravity
- Quick disconnects
- Animal handling techniques
- Cage volume required for animal well-being
- Disposable-element habitat designs

SUMMARY

The baseline designs for a Restrained Squirrel Monkey Habitat and an Unrestrained Squirrel Monkey Habitat meet most of the primary requirements. Areas which pose design challenges are summarized below.

WASTE MANAGEMENT SYSTEM

The design of an efficient waste management system is a challenge to be met in order to provide a living environment that is conducive to the animals' health and well being.

TEMPERATURE AND HUMIDITY CONTROL

The environmental control within $\pm 1^{\circ}\text{C}$ may be very difficult to meet due to fluctuating conditions of Space Station Freedom air, random water additions and evaporation in the specimen chamber. An airflow and environmental control testbed is being developed at ARC to help examine this issue.

UNIFORM AIRFLOW

At low airflow rates, achieving uniform airflow inside the specimen chamber to within $\pm 5\%$ will be very difficult. The airflow/environmental test bed mentioned above will assist in understanding the system's airflow characteristics.

ACOUSTIC NOISE LEVEL

Acoustic noise was not addressed in this study. It needs to be addressed in future habitat studies as the effect of prolonged exposure to noise levels, even moderate levels, is a concern.

MODULAR AND DISPOSABLE ELEMENTS

Serviceable habitat elements should be modular and disposable, whenever possible, to minimize the required crew time. For this reason, trade studies on serviceable elements should be performed in order to understand the benefits, impacts, and feasibility in making serviceable elements modular and disposable.

SUMMARY

The habitats meet the requirements except as noted. Most technology has previously been demonstrated.

- Waste management system developed within volume constraints
- Temperature and humidity control
- Uniform airflow
- Acoustic noise level
- Modular and disposable elements

SUMMARY (CONT'D)

ANIMAL HANDLING TECHNIQUES

The limited reach and vision into the specimen chamber for operations may pose difficulties. Additional studies should be done to find or develop a method of animal capture that has little impact on the habitat design and requires minimal operator training while meeting the animal handling requirements.

MINIMUM FLOOR SPACE REQUIREMENT

Differences in the floor space requirements between the Science Accommodation Requirement and the NIH guidelines must be reconciled. Studies will be done to determine floor space and volume requirements which satisfy both animal well-being and research requirements.

BEHAVIOR ENRICHMENT

In addition to the feeder tap switch, other behavior enrichment methods should be considered.

UNIQUE DESIGN FEATURES

The Restrained Squirrel Monkey Habitat will require development of: the restraint chair, restraint accessories, and the fluid sample carousel. These are similar to the RAHF design but are still not proven in space flight.

The dual specimen orientation will require further development in the water lixit and feeder designs to maintain ease of operation and experiment flexibility.

Many of the components developed for the Unrestrained Squirrel Monkey Habitat can and should be used in developing the Restrained Squirrel Monkey Habitat.

SUMMARY (CONT'D)

Most systems of the Unrestrained Squirrel Monkey Habitat are common with the Restrained Squirrel Monkey Habitat. However differences exist in the following areas:

- Animal Handling Techniques
- Floor Space Requirements
- Behavior Enrichment Techniques
- Unique Design Features for Restraint Systems

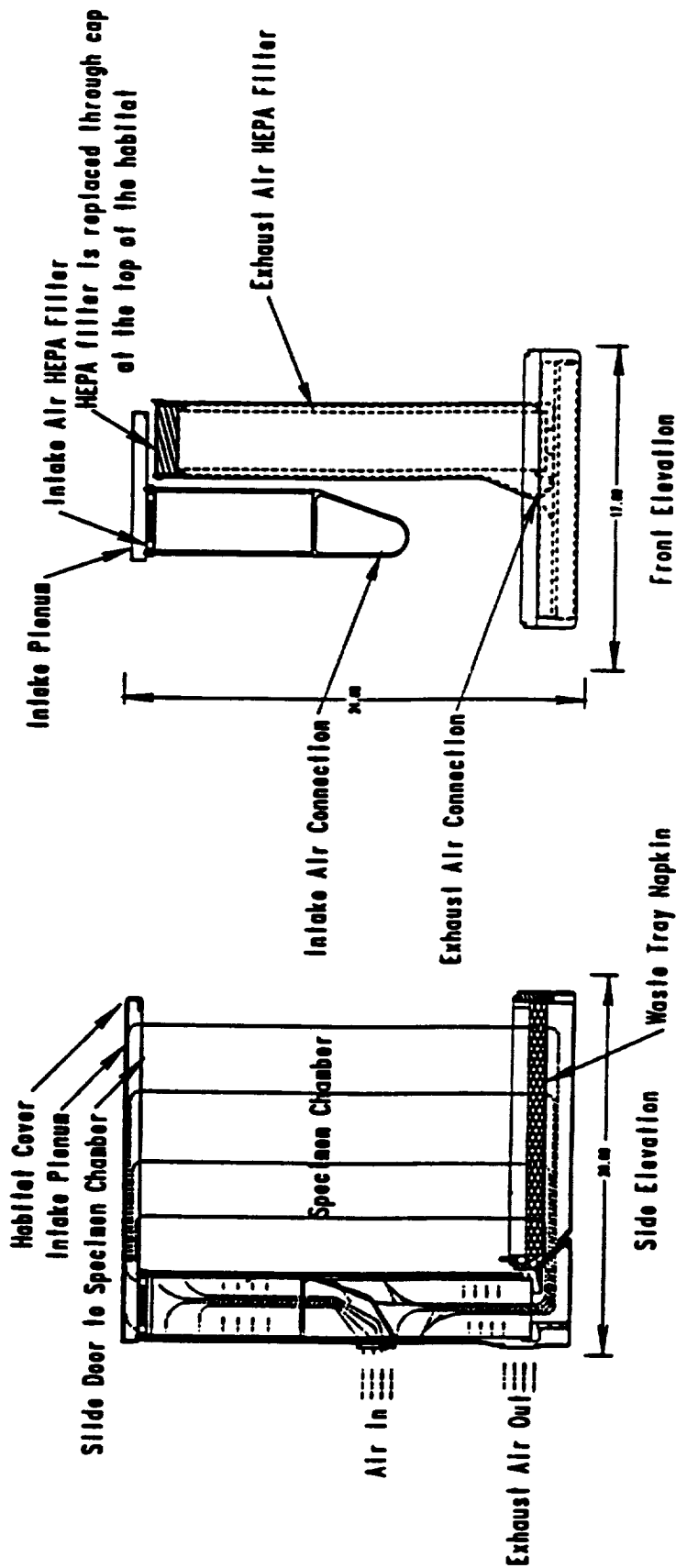
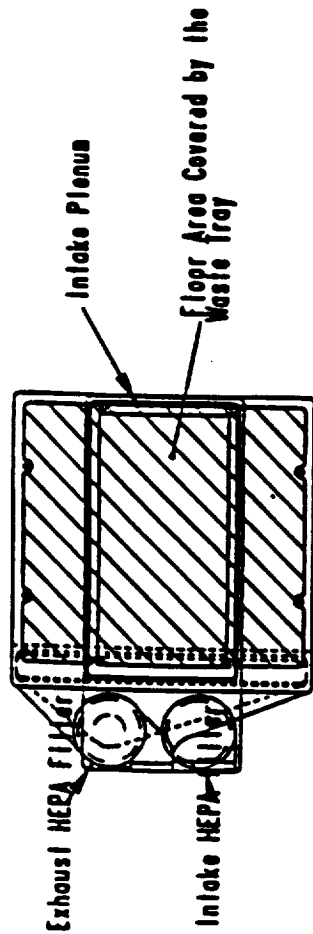
APPENDIX

- 1) Orthographic views on the habitats are presented for more detail.
- 2) Supplementary material for integrated perch and squeeze wall design is included.
- 3) Additional trade study materials on perch designs and orthographic views of the dual position chair are also included for reference.
- 4) The operational procedure summaries for some of the more common operations are included in the appendix. They demonstrate operational constraints within the Glovebox and the crew intensive nature of any Glovebox operation.
- 5) Unrestrained Squirrel Monkey Perch Design Matrix.

APPENDIX

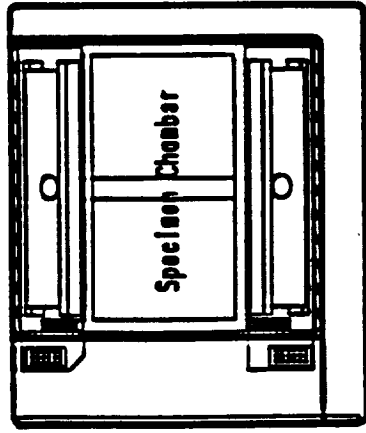
- 1) Orthographic Views
- 2) Integrated Perch and Squeeze Wall
- 3) Dual Position Chair.
- 4) Operations:
 - Unrestrained Monkey Specimen Chamber Cleaning
 - Unrestrained Monkey Food Replenishment
 - Unrestrained Monkey Specimen Weight
 - Restrained Monkey Waste Tray Change-out
- 5) Unrestrained Squirrel Monkey Perch Design Matrix

ORTHOGRAPHIC HABITAT VIEWS

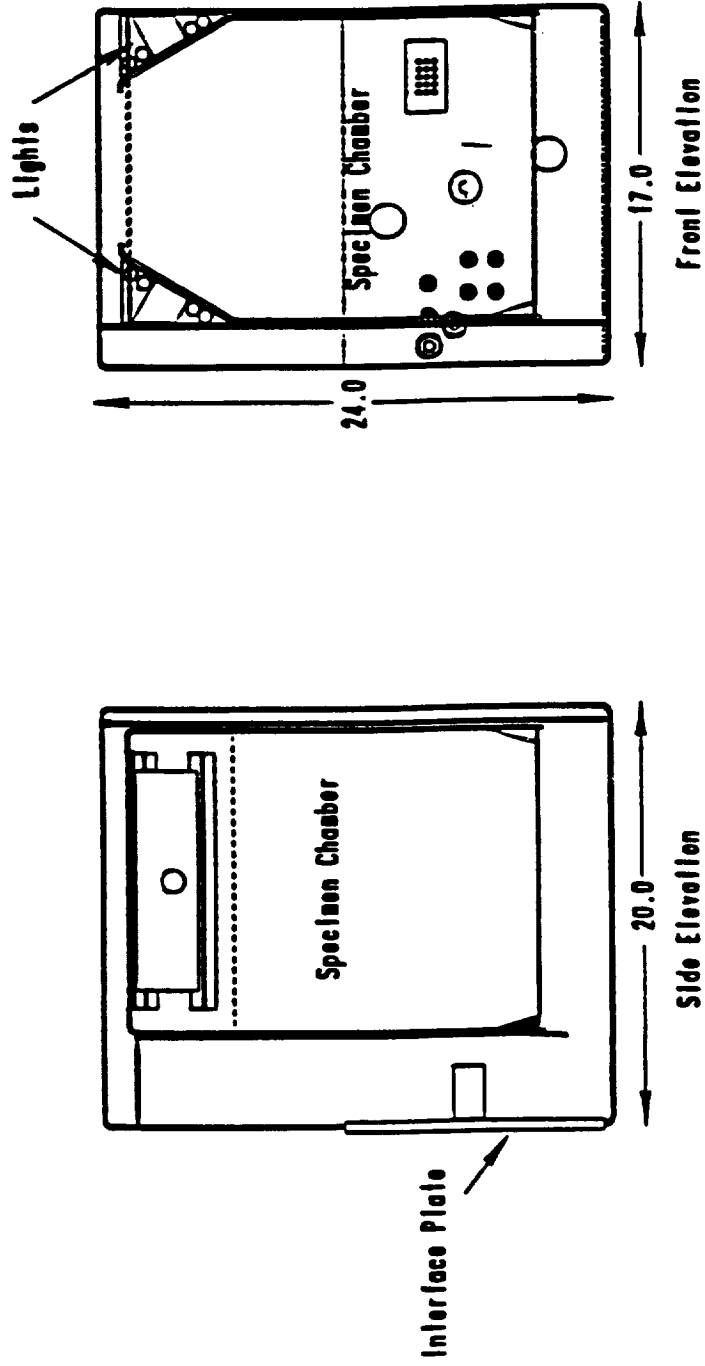


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ORTHOGRAPHIC HABITAT VIEWS

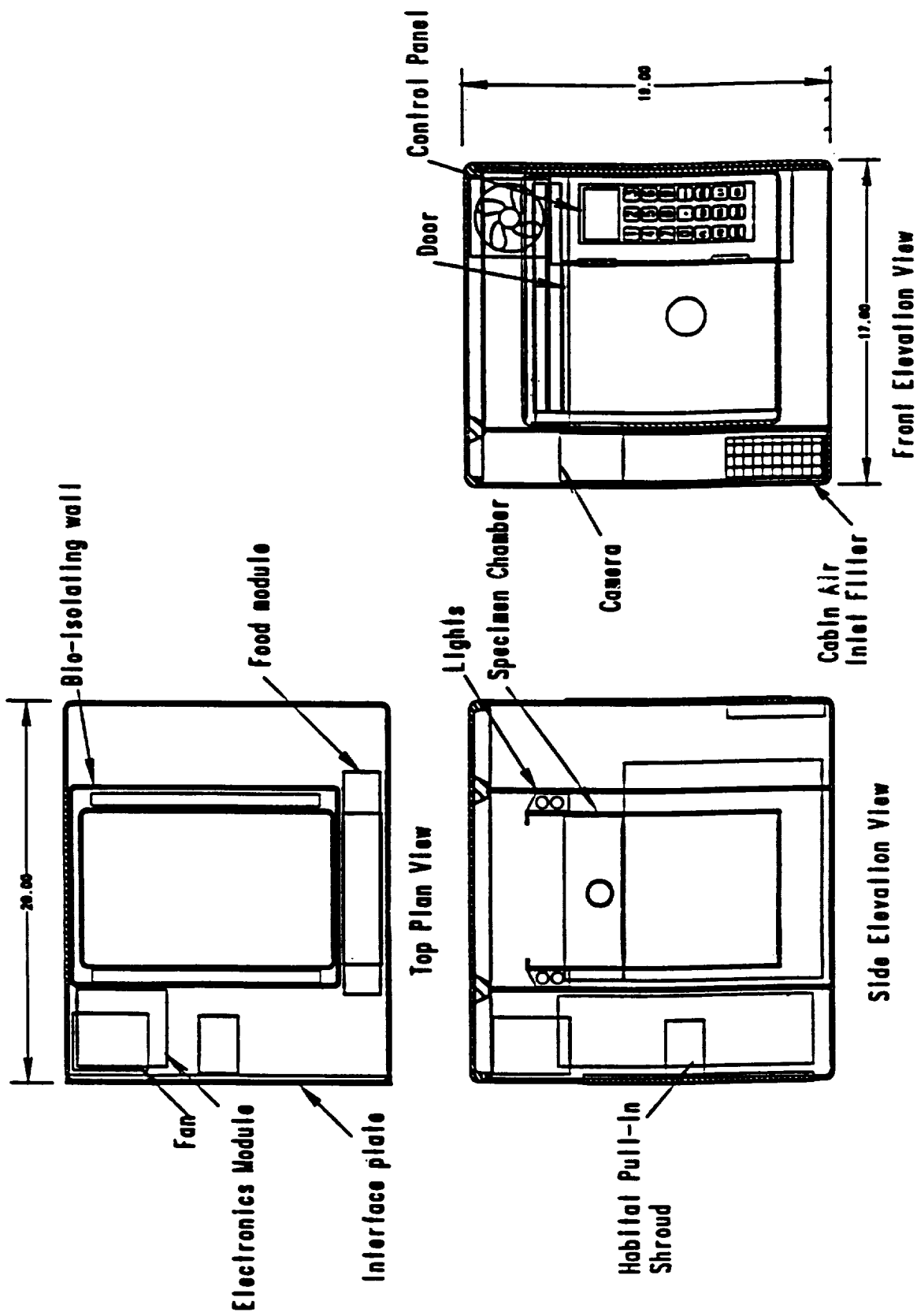


Top Plan



Unrestrained Habitat Enclosure and Specimen Chamber

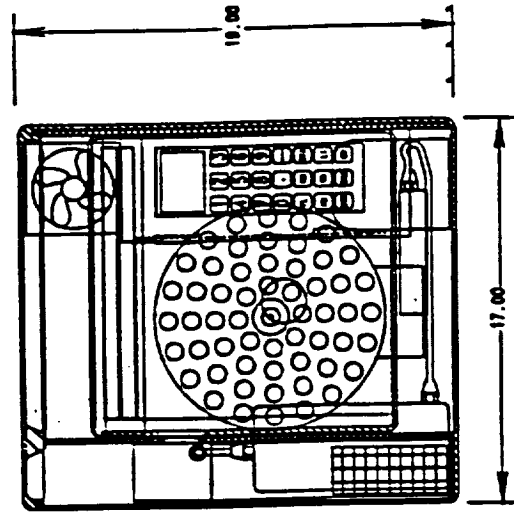
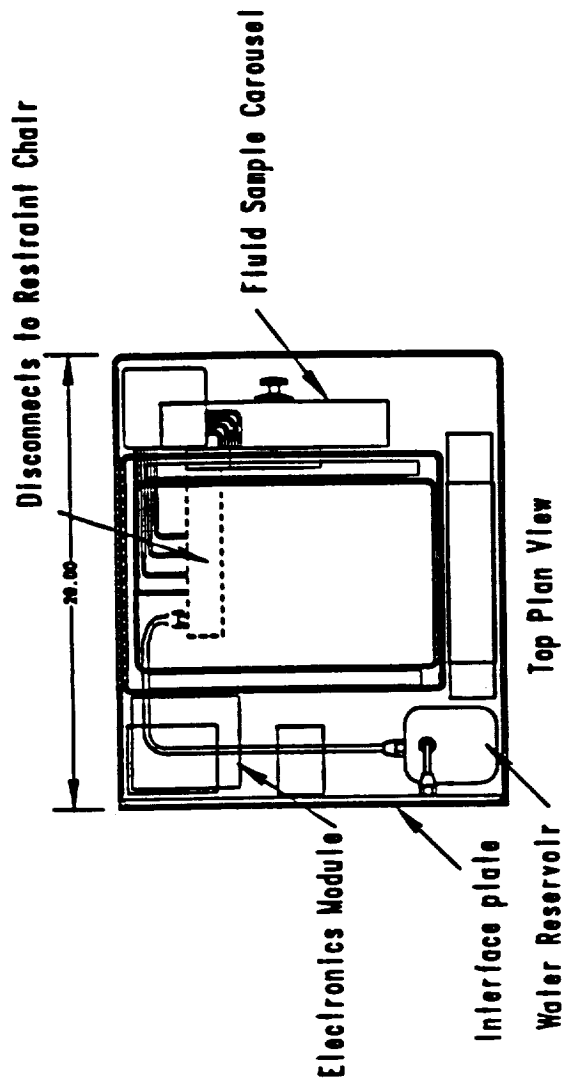
ORTHOGRAPHIC HABITAT VIEWS (CONT'D)



Restrained Habitat Enclosure and Specimen Chamber

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ORTHOGRAPHIC HABITAT VIEWS (CONT'D)

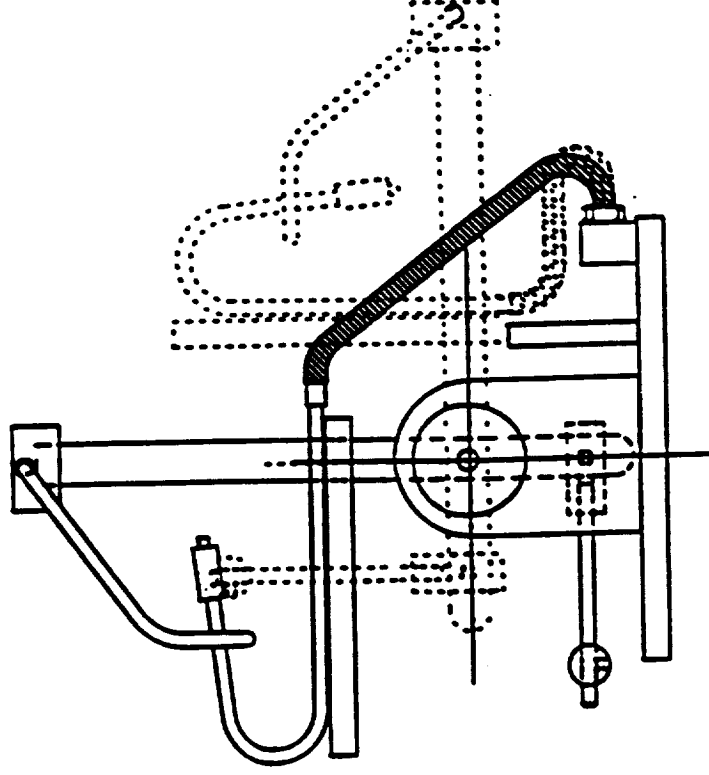


Restrainted Habitat Fluid Systems

DUAL ORIENTATION RESTRAINT CHAIR

The adjacent page depicts a side view of one concept for a dual orientation restraint chair. The dotted lines indicate a position of the chair which is orthogonal to the upright position in solid lines.

DUAL ORIENTATION RESTRAINT CHAIR

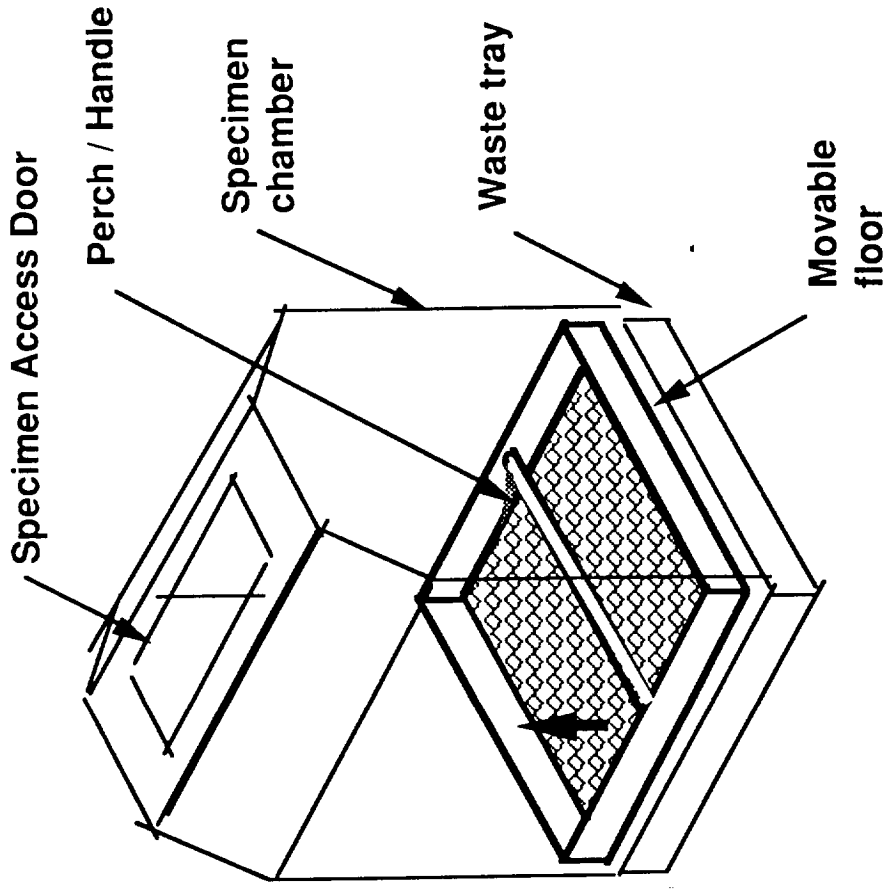


Dual-Orientation Restraint Chair

INTEGRATED PERCH AND SQUEEZE WALL

During Glovebox operations, an aid for capturing and handling the animal will be necessary due to the physical constraint required to reach into the habitat from the Glovebox and to limited visibility of the animal. The Perch and Squeeze Wall design, illustrated in the sketch on the facing page, is designed specifically for such tasks. The perch is attached to the squeeze wall and used to draw the wall towards the top of the chamber, forcing the monkey to move closer to the access door.

INTEGRATED PERCH AND SQUEEZE WALL



A tool lowered into the specimen chamber through the specimen access door engages the perch/handle and raises the floor forcing the monkey to the specimen access door

OPERATIONS

UNRESTRAINED SPECIMEN CHAMBER CLEANING

Equipment required: Glovebox, cage cleaner, waste tray napkin, additional habitat, animal capture tools, and a bag.

Procedure:

1. Initialize Glovebox.
2. Install fresh habitat in Glovebox bay #1.
3. Install habitat with specimen, in the second Glovebox bay.
4. Open the external door of the habitat in Glovebox bay #1, remove and store the intake plenum in the Glovebox volume, and open specimen chamber door.
5. Open external habitat door at bay #2, remove intake plenum, and store in the Glovebox work volume.
6. Open specimen chamber door at bay #2, capture monkey and transfer to the clean habitat at bay #1.
7. Shut the specimen chamber door at bay #1, and reinstall the intake plenum.
8. Shut the external habitat door, return the habitat with monkey to the Holding System.

OPERATIONS

UNRESTRAINED SPECIMEN CHAMBER CLEANING

9. Bring a cage cleaner kit inside an equipment transfer module to Glovebox bay #1.
10. Disconnect (at bay #2) specimen chamber connections to the lighting modules food module, water module and electronics.
11. Remove specimen chamber from the habitat into the Glovebox work volume.
12. Prepare the specimen chamber for washing; remove and clean sensors, seals, inspect chamber interior.
13. Disconnect exhaust plenum remove from the Glovebox work volume through a gloveport.
14. Bag waste tray napkin for storage and remove from the Glovebox work volume through a gloveport.
15. Remove equipment transfer module from bay #1.
16. Attach wash module to Glovebox bay #1, remove door, and transfer dirty specimen chamber into the wash module.
17. Close wash module and remove from the Glovebox to the cage cleaner queue.

OPERATIONS

UNRESTRAINED SPECIMEN CHAMBER CLEANING

18. Clean and inspect exhaust plenum, and other equipment as necessary in the Glovebox.
19. Insert clean specimen chamber in equipment transfer module, and install in Glovebox bay #1.
20. Open equipment transfer module door and transfer clean specimen chamber to the Glovebox.
21. Inspect clean specimen chamber, install sensors which may have been removed prior to cleaning.
22. Transfer clean waste tray napkin into the Glovebox, through a gloveport, and install in the waste tray.
23. Install waste tray, napkin and exhaust plenum onto the clean specimen chamber.
24. Check specimen chamber-waste tray assembly for proper operation.
25. Install the specimen chamber into the clean habitat at bay #2.
26. Reconnect and check specimen chamber food, water, and the electronics module connections.

OPERATIONS

UNRESTRAINED SPECIMEN CHAMBER CLEANING

27. Reinstall lighting modules in the habitat.
28. Reinstall intake plenum in the habitat, check seals.
29. Check airflow and lighting within the habitat.
30. Close habitat external door, remove clean habitat from the Glovebox and return to the storage.
31. Clean Glovebox volume.

OPERATIONS

Unrestrained Food Replenishment

Equipment required: Glovebox, food cannister, bag.

Procedure:

1. Initialize Glovebox.
2. Place food cannister and bag in an equipment transfer module and install module in the Glovebox.
3. Remove habitat from the Holding System Glovebox and install in empty Glovebox bay.
4. Open habitat external door.
5. Remove spent food cannister from the food module and install new cannister.
6. Bag empty cannister, remove from Glovebox through a gloveport for storage.
7. Close habitat external door and return habitat to the Holding System.
8. Clean Glovebox work volume.

OPERATIONS

UNRESTRAINED SPECIMEN WEIGHT

Equipment required: Glovebox, mass measurement device, specimen capture tools, and the specimen restraint box

Procedure:

1. Initialize Glovebox.
2. Place measurement device, specimen capture tools, and the specimen restraint box in an equipment transfer module and install module into an empty Glovebox bay.
3. Remove habitat from the Holding System and install in empty Glovebox bay.
4. Open habitat external door and remove intake plenum to the Glovebox.
5. Open specimen chamber door, capture monkey using animal capture tools.
6. Place monkey in restraint box.
7. Weigh monkey and restraint box on the mass measurement device.
8. Remove monkey from the restraint box and return to the specimen chamber.
9. Close specimen chamber door, reinstall intake plenum.
10. Shut habitat external door and return habitat to the Holding System.
11. Clean Glovebox volume.

OPERATIONS

Restrained Habitat Waste Tray Change-out

Equipment Required: Glovebox, clean waste tray liner, bag

Procedure:

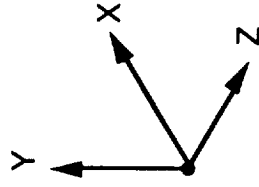
1. Initialize Glovebox.
2. Place a clean waste tray liner and bag into an equipment transfer module and install module in the Glovebox.
3. Remove habitat from the Holding System and install habitat in the empty Glovebox bay.
4. Open external habitat door and remove intake plenum to the Glovebox.
5. Open specimen chamber door and lift restraint chair (with monkey) into the Glovebox.
6. Disconnect specimen chamber food module, water module, lights, and electronics connections.
7. Lift specimen chamber from the habitat into the Glovebox.
8. Detach waste tray and exhaust plenum from the specimen chamber.
9. Remove used waste tray liner, place in waste bag and seal.

OPERATIONS

Restrained Habitat Waste Tray Change-out

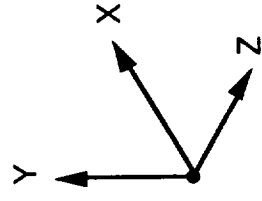
10. Vacuum and / or brush specimen chamber floor to remove any loose debris.
11. Install a clean waste tray liner into the waste tray.
12. Reinstall waste tray and exhaust plenum onto the specimen chamber.
13. Check seal integrity between specimen chamber, waste tray, and the exhaust plenum.
14. Reinstall assembled specimen chamber in the habitat, restore connections to food, water, lights, and the electronics module.
15. Return restraint chair (with animal) to the habitat and lock in place.
16. Check water and fluid lines to the specimen carrier.
17. Close specimen chamber door, reinstall intake plenum in the habitat, and check seals.
18. Check airflow and lighting within the habitat.
19. Close external habitat door and return habitat to the holding system.
20. Remove bagged dirty waste tray liner from the Glovebox through a gloveport, and store.
21. Clean Glovebox work volume.

PERCH DESIGN MATRIX



| Description | • Z axis | • Z axis | • X axis | • X axis |
|-------------|---|---|---|---|
| Evaluation | • 1 Mounting point | • 2 Mounting points | • 2 Mounting points | • 1 Mounting point |
| | • 1 open end | • No open ends | • No open ends | • 1 open end |
| | + Simple Design | + Simple Design | + Simple Design | + Simple Design |
| | + Minimal waste trapping | + Minimal waste trapping | + Minimal waste trapping | + Minimal waste trapping |
| | + Smallest chamber volume penalty | + Small chamber volume penalty | + Small chamber volume penalty | + Smallest chamber volume penalty |
| | + Compatible with "squeeze wall" animal capture | + Compatible with "squeeze wall" animal capture | + Compatible with "squeeze wall" animal capture | + Compatible with "squeeze wall" animal capture |
| | + Chain tether may be used | - 1 axis functionality | - 1 axis functionality | + Chain tether may be used |
| | - 1 axis functionality | - Perch must span floor | - Use of a chain tether may pose a hazard to animal | - 1 axis functionality |
| | - Additional structure may be required to support | - Use of a chain tether may pose a hazard to animal | | |

PERCH DESIGN MATRIX



Description



- | | | | |
|---|--|---|---|
| <ul style="list-style-type: none"> • X-Z axes • 2 Mounting points • No open ends | <ul style="list-style-type: none"> • X-Z axes • 1 Mounting point • 1 open end | <ul style="list-style-type: none"> • X-Y axes • 2 Mounting points • No open ends | <ul style="list-style-type: none"> • X-Y axes • 1 Mounting points • 1 open end |
|---|--|---|---|

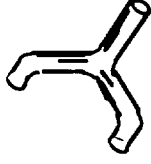
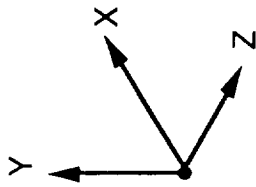
Evaluation

- | | | | |
|---|---|---|---|
| <ul style="list-style-type: none"> + Simple Design + Minimal waste trapping + 2 axis functionality + Small chamber volume penalty | <ul style="list-style-type: none"> + Simple Design + Minimal waste trapping + 2 axis functionality + Small chamber volume penalty | <ul style="list-style-type: none"> + Simple Design + Minimal waste trapping + 2 axis functionality + Small chamber volume penalty | <ul style="list-style-type: none"> + Simple Design + Minimal waste trapping + 2 axis functionality + Small chamber volume penalty |
|---|---|---|---|

Baseline chosen is the best compromise of functionality and design impacts

- | | | | |
|--|--|--|--|
| <ul style="list-style-type: none"> + Compatible with "squeeze wall" animal capture - Use of a chain tether may pose a hazard to animal | <ul style="list-style-type: none"> + Compatible with "squeeze wall" animal capture + Chain tether may be used - Additional structure may be required to support | <ul style="list-style-type: none"> - Use of a chain tether may pose a hazard to animal - Not compatible with "squeeze wall" animal capture | <ul style="list-style-type: none"> + Chain tether may be used - Not compatible with "squeeze wall" animal capture - Additional structure may be required to support |
|--|--|--|--|

PERCH DESIGN MATRIX



| Description | <ul style="list-style-type: none"> • X-Y-Z axis • 3 Mounting points • No open ends | <ul style="list-style-type: none"> • X-Y-Z axis • 2 Mounting points • 1 open end | <ul style="list-style-type: none"> • X-Y-Z axis • 2 Mounting points • 1 open end | <ul style="list-style-type: none"> • X-Y-Z axis • 2 Mounting points • 1 open end | <ul style="list-style-type: none"> • X-Y-Z axis • 1 Mounting point • 2 open ends |
|-------------|--|--|--|--|---|
| Evaluation | <ul style="list-style-type: none"> + 3 axis functionality - Greater chamber volume penalty - Complex Design - Not compatible with "squeeze wall" animal capture - Use of a chain tether may pose a hazard to animal - Increased waste trapping | <ul style="list-style-type: none"> + 3 axis functionality - Greater chamber volume penalty - Complex Design - Not compatible with "squeeze wall" animal capture - Use of a chain tether may pose a hazard to animal - Increased waste trapping | <ul style="list-style-type: none"> + 3 axis functionality - Greater chamber volume penalty - Complex Design - Not compatible with "squeeze wall" animal capture - Use of a chain tether may pose a hazard to animal - Increased waste trapping | <ul style="list-style-type: none"> + 3 axis functionality - Greater chamber volume penalty - Complex Design - Not compatible with "squeeze wall" animal capture - Use of a chain tether may pose a hazard to animal - Increased waste trapping | <ul style="list-style-type: none"> + 3 axis functionality + Chain tether may be used - Greater chamber volume penalty - Complex Design - Not compatible with "squeeze wall" animal capture - Increased waste trapping |

CENTRIFUGE FACILITY SYSTEM STUDY

Chapter 4

Plant Habitat

PLANT HABITAT INTRODUCTION

The materials in this chapter of the report reflect the NASA - Ames in-house system study effort to design a Plant Habitat.

An outline of the Plant Habitat chapter for the system study is provided on the facing page.

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PLANT HABITAT OUTLINE

- PRIMARY REQUIREMENTS
- HABITAT DESCRIPTION
- HABITAT CHARACTERISTICS
- EXTERNAL INTERFACES
- TRADEOFFS
- OPERATIONAL SUMMARY
- REQUIREMENTS NOT MET
- TECHNOLOGY DEVELOPMENT
- SUMMARY

PRIMARY REQUIREMENTS

The facing page is a list of requirements which must be satisfied by a plant habitat. The requirements were derived from the needs of plant physiologists and limitations specific to the overall Centrifuge Facility design. The letters in the right hand column on the facing page represent an assessment of whether or not the requirements are met by this design concept.

It appears that maintaining the temperature between 15°-30°C will not be difficult. However, the ability to control the temperature to $\pm 1^\circ\text{C}$ will be a function of the air flow rate and light intensity. As the air flow rate decreases, the response time for temperature control increases. Therefore, it will be difficult to control temperature variation to $\pm 1^\circ\text{C}$, especially at low flow rates.

The atmospheric composition of the plant chamber can be adjusted over a wide range to accommodate a variety of growing conditions. For most experiments, O₂ levels will be maintained around 20-25%. However, for certain crops such as wheat, growth rates can be increased when O₂ is reduced to 5%.

CO₂ compositions of 300-5000 ppm are standard for plant growth.

Because ethylene buildup could alter the growth pattern of most plants, a requirement to maintain ethylene to less than 5 ppb has been imposed. However, current technology limits measurement of ethylene to about 50 ppb so it will be necessary to provide a method of continuous scrubbing of the atmosphere to maintain ethylene levels of below 5 ppb.

Low air flow rates of 0-10 air changes per hour are required to reduce the induced mechanical perturbations to the plants since these forces can confound test results. It is unknown at this time if a uniform air flow velocity can be maintained to within 5%, over a wide range, at any point in the plant chamber.

Providing relative humidity of 40-80% is standard for most ground based plant growth chambers. Maintaining a humidity level to $\pm 10\%$ will depend on the air flow rate, air temperature, and transpiration rate of the plant. Higher levels of humidity should be easier to maintain than lower levels.

PRIMARY REQUIREMENTS

| | | |
|---|---|-------------|
| <ul style="list-style-type: none"> Temperature range: | 15°C to 30°C ± 1°C | Status P |
| <ul style="list-style-type: none"> Atmosphere composition: | O2 5-27% ± 0.5% CO2 300-5000 ppm Ethylene < 5 ppb | U |
| <ul style="list-style-type: none"> Air velocity | 0-10 changes/hr ± 5% uniform to ±5% | U |
| <ul style="list-style-type: none"> Humidity | 40% to 80% RH ± 10% | P |

M=Met P=Partially Met N=Not Met U=Unknown

PRIMARY REQUIREMENTS (CONT'D)

The requirement to provide irradiation of 0-600 $\mu\text{mole/m}^2/\text{s}$ is a compromise between current lighting technology limits, heat transfer capability, and plant growth needs. For comparison, noon-day-sun at the equator is equivalent to approximately 2000 $\mu\text{mole/m}^2/\text{s}$.

The nutrient delivery system must accommodate either a solid matrix or hydroponics system to provide flexibility in experimentation. Hydroponic and solid matrix nutrient delivery are baselined for the Plant Habitat. The shells of the nutrient trays are modular to accommodate hardware for hydroponics or solid matrix.

The requirements state that the specimen chambers shall be capable of supporting experiments from 0-90 days without disturbance. This is accomplished by plumbing water and gases from the Holding Unit or Centrifuge to the habitat. There are five nutrient reservoirs which can be replenished from the front of the Plant Habitat without disturbing the plant chambers.

Video images of the plants must be transmitted to a ground station to allow the investigators to monitor and record the experiments as necessary. To view plants growing in darkness, infra-red video or colored filters over the viewing ports are required.

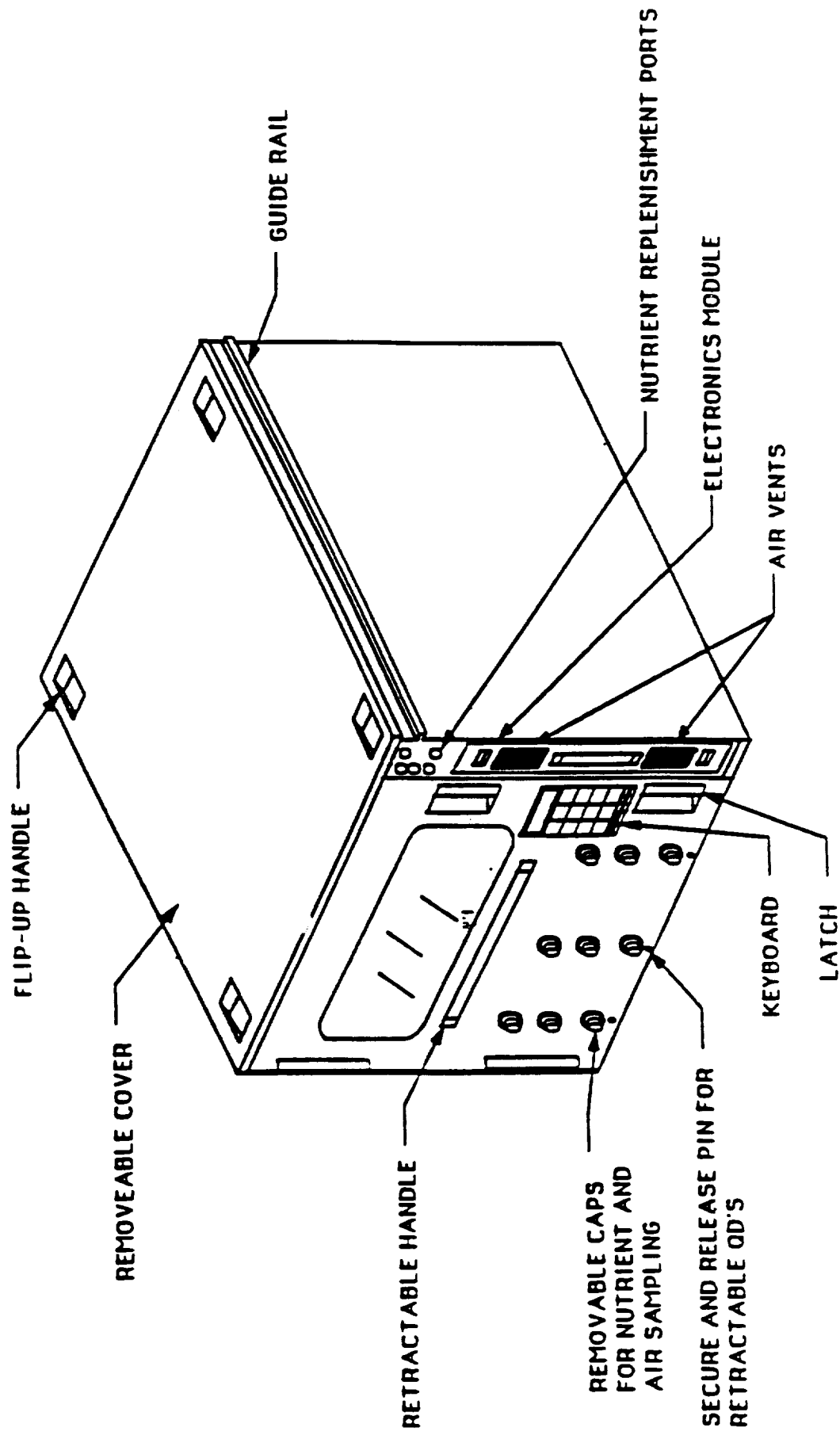
PRIMARY REQUIREMENTS (CONT'D)

| | | status |
|---|---|--------|
| • Irradiation | photon flux 0-600 $\mu\text{mole/m}^2/\text{s} \pm 5\%$ | U |
| • Nutrients | solid matrix or liquid medium | M |
| • Nutrient delivery system | continuous flow capability | M |
| | independent delivery and replenishment of liquid nutrient media | |
| • Specimen chamber configuration | 38 cm (15") growing height (adjustable root/shoot ratio) 200 in ² growing area capability for subdividing growing area | M |
| • Experiment duration | capability to support experiments up to 90 days | P |
| • Monitoring | video observation with color, b/w, IR monitor environmental parameters | M |
| M=Met P=Partially Met N=Not Met U=Unknown | | |

DESIGN DESCRIPTION

An isometric view of the Plant Habitat is shown on the facing page. This isometric view shows the approximate locations and configuration of the habitat's hardware such as the electronics module, removable cover, gas and nutrient sampling ports, and input keyboard.

PLANT HABITAT ISOMETRIC VIEW



DESIGN DESCRIPTION (CONT'D)

The following pages present the design features of the Plant Habitats. The external structure of the habitat provides a primary level of bioisolation and houses either one large plant chamber or three small plant chambers. The plant chambers provide a second level of bioisolation. An experimenter has the option of using a large plant chamber with 1,290 cm² (200 in²) of growing area or three smaller chambers, each with 387 cm² (60 in²) of growing area. The plant chambers can be individually removed and transported to the Life Sciences Glovebox (LSG) without disturbing the remaining plant chambers in the habitat.

Located on the front door are nine ports used for sampling the nutrient solution and atmospheric composition within each of the plant chambers. To take samples, protective caps are unscrewed and a syringe is inserted through a self sealing rubber diaphragm in the front of the plant chamber. Also included on the front door is a keypad to input commands to the habitat. The keypad can also be used to access information about individual components and aid in troubleshooting. All items such as door latches and handles will be retractable to reduce the number of protrusions on the front surface exposed to the cabin.

DESIGN DESCRIPTION (CONT'D)

- 2 levels of bioisolation
- Habitat size: 43cm wide x 51cm deep x 48cm high (17" x 19" x 20")
- Growing volume: 1 chamber with 1,290 cm² (200 in²) floor x 38 cm (15") high
3 chambers, each 387cm² (60 in²) x 38 cm (15") high
- Sampling ports in front
- Transportable specimen chamber
- Data display and input terminal on front

DESIGN DESCRIPTION (CONT'D)

Located on the front upper right corner of the habitat are five ports for refilling the five, 50 ml nutrient reservoirs. These reservoirs will contain acid and base solutions required by the experimenter. Water for replenishing the 750 ml reservoir is supplied through the rear of the habitat. The nutrient delivery system is designed to be versatile enough to accommodate a hydroponic system in addition to recirculating fluid through a solid matrix. The 750 ml reservoir can accept water from the holding system thru the rear of the habitat. The water quality desired is 18 M Ω to allow better control of nutrient ion content and pH. The reservoir has an internal mixer, heater, and sensors for measuring pH, conductivity, and oxygen concentration. Sampling of the nutrient reservoir is possible via a tube running to the top of the habitat. If the reservoir becomes contaminated, its contents can be drained into the waste water line of the holding system. The nutrient solution is recirculated by means of a self priming pump. Five 50 ml reservoirs with pressurized bladders hold a variety of acid and base solutions which provide the ions required for a standard Hoagland's solution. These reservoirs can be refilled from the front of the habitat.

Individual gas lines of O₂, N₂, and CO₂ are provided so that experimenters have the option of adjusting atmospheric composition.

Under normal growing conditions, the air within the plant chamber would be recycled through a set of ducts located in the rear of the habitat. As the plants generate oxygen, air is bled out of the plant chamber and N₂ is added to maintain the overall concentration of O₂.

To control ethylene buildup generated by the plants, a Purafil cartridge is provided to continuously scrub the air.

An adjustable 3-axis accelerometer is located on the rear wall of the plant chamber. Its purpose is to measure vibration levels within the plant chamber. The accelerometer is located on a track so that it can be positioned with respect to the height of the nutrient tray.

DESIGN DESCRIPTION (CONT'D)

- Replenishment of nutrient solution by 5 stock solutions
- Gas composition controlled by a combination of a selective gas trap and a bleed-out system, CO₂ binding by LiOH, resupply with bottled N₂, CO₂, O₂, ethylene binding with Purafil
- Standard interface plate for electronics, O₂, CO₂, N₂, water, waste air, waste liquid & cooling water
- Ability to exchange functional units for service and repair
- Removable lighting module for taller specimen chamber
- Lighting by LEDs, IR-LEDs for dark cycle illumination
- Video observation with color and IR lens
- Interchangeable nutrient delivery systems
- Variable root and shoot zone ratio
- Semi-closed loop life support system
- One, 3 axis accelerometer at root/shoot interface of plant chamber to measure vibration

DESIGN DESCRIPTION (CONT'D)

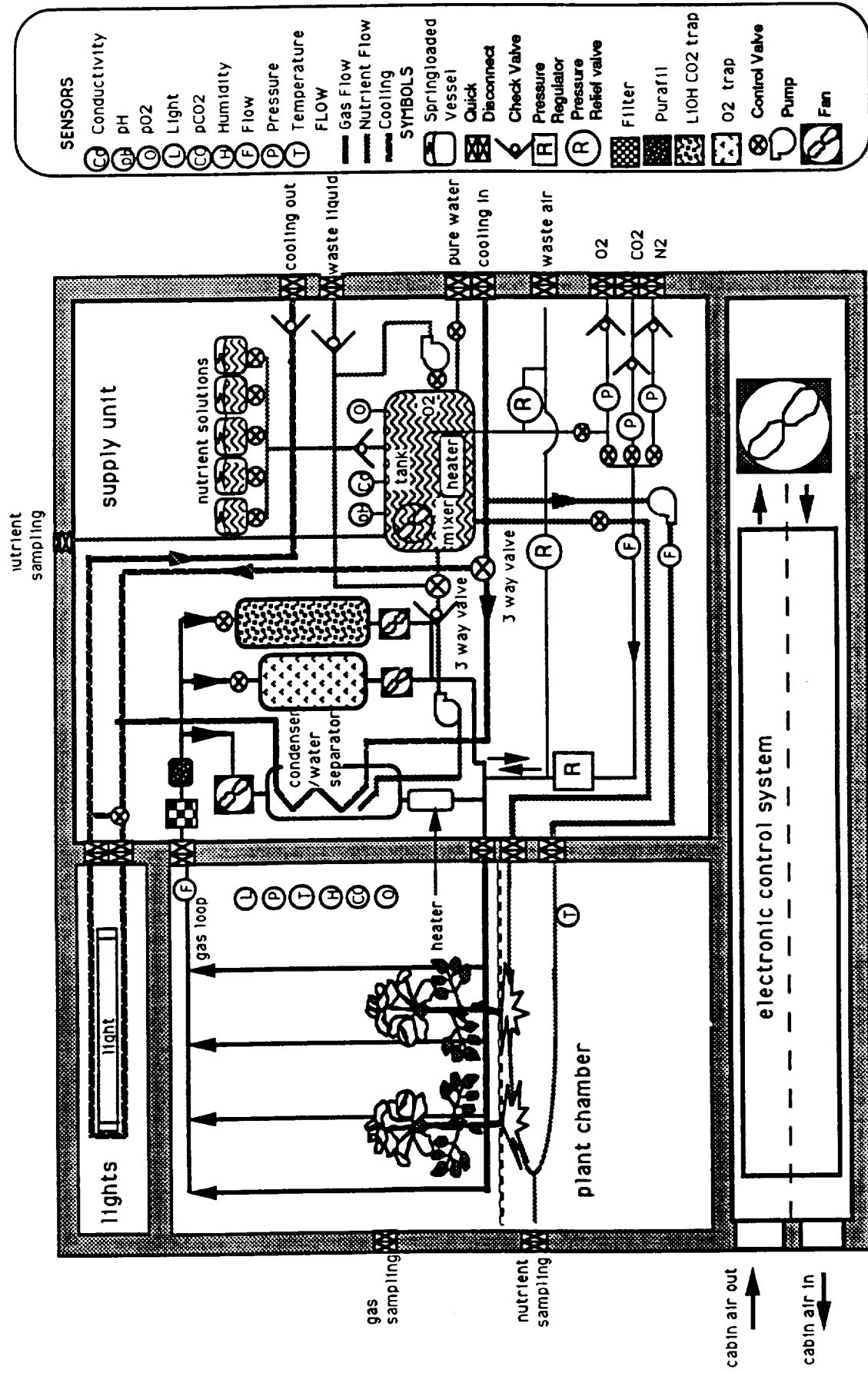
The plant habitat block diagram illustrates the functional design of the Plant Habitat. The gas supply system shows incoming lines for O₂, CO₂, and N₂. These lines enter a manifold in the rear of the habitat. This manifold is equipped with a check valve, pressure sensor and electrically actuated valve for each incoming gas line.

An additional line branches off the incoming O₂ line to oxygenate the nutrient reservoir; oxygenation is accomplished by O₂ diffusion into the nutrient solution at a preset pressure. A relief valve prevents over pressurization and safely discharges oxygen into the waste air line. A flow meter on the outlet side of the manifold measures the amount of gas injected into the system. The regulator maintains air pressure at 1 atmosphere (14.7 psi). Most of the time, air is recirculated through the a main duct in the service module. This duct contains a coarse air filter and an ethylene filter at the inlet. Three, 3" diameter fans draw air through the filters past a heat exchanger/condenser air-water separator. Water collected from the condenser is pumped back into the nutrient reservoir to be reused. A heater is located near the exit of the duct to preheat the air if necessary. An O₂ scrubber and CO₂ scrubber are provided in the air recirculating system to adjust composition of the air without continually purging the system to reduce gas consumption. Each scrubber has a 3" diameter fan to overcome pressure losses.

The nutrient delivery system has five 50 ml reservoirs to store acids and bases. Each reservoir is plumbed to a large 750 ml reservoir. Fluid contained in this reservoir can be heated or oxygen concentration can be monitored and controlled. A peristaltic pump recirculates fluid through the plant growth trays. The nutrient delivery system can support either hydroponics or porous tubing in an inert growth medium. Contaminated fluids can be pumped from the system and fresh water added as required.

Cooling water provided by the Holding Unit is used to chill the recirculated air from the plant chamber. A 3-way valve, located at the start of the cooling loop, can bypass coolant to the air duct if air temperatures in the plant chamber are stable. The cooling water is also plumbed to extract heat from the lighting module. If the lighting module is not required, a bypass loop is created using a 3-way valve located near the lighting module.

PLANT HABITAT BLOCK DIAGRAM



DESIGN DESCRIPTION (CONT'D)

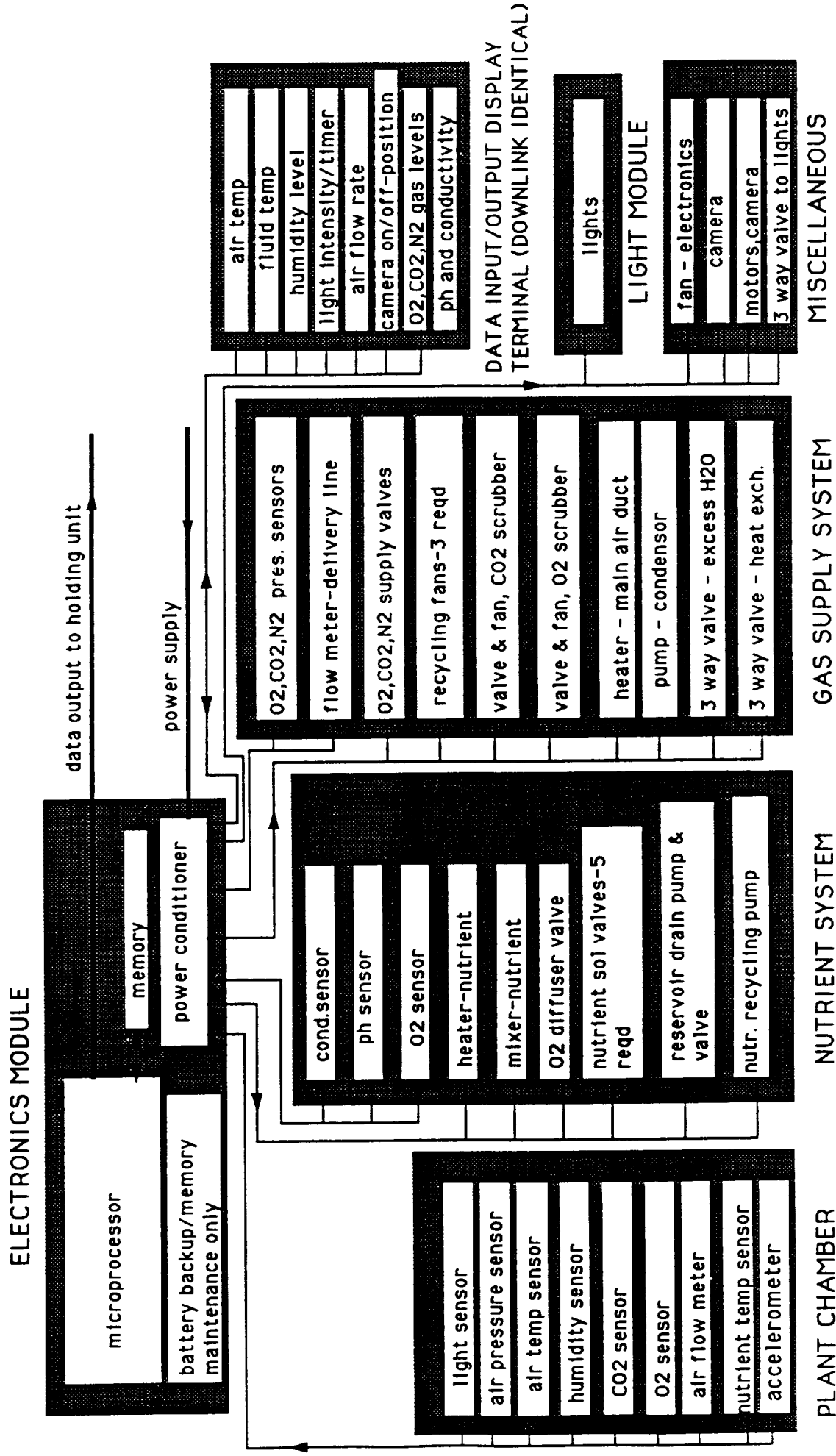
The electrical block diagram on the facing page lists the components in the habitat control system. Power in the form of 28 Vdc is supplied from the Holding Unit, Centrifuge or Glovebox to the Plant Habitat. Incoming power is sent through a power conditioner to pumps, valves, sensors, etc. within the habitat. A microprocessor controls habitat functions including environmental control, lighting and nutrient control. A nonvolatile memory is provided to protect the system when power is interrupted during transfer of the Plant Habitat from the Holding System or Centrifuge to the Glovebox.

Instructions can be preprogrammed into the Plant Habitat via ground based computer link or from the input keypad located on the front door of the Plant Habitat. Input parameters include air temperature and composition, humidity, flow rate for both air and nutrient solution, pH and conductivity of nutrient solution, photoperiod and intensity of lighting, and video transmission.

Approximately thirteen sensors are located within the Plant Habitat. The microprocessor, along with the signal conditioning electronics monitors conditions within the plant chamber, the nutrient delivery system, and the gas supply system and actuates valves, fans, and heaters as required to maintain the preprogrammed environment.

C. 4

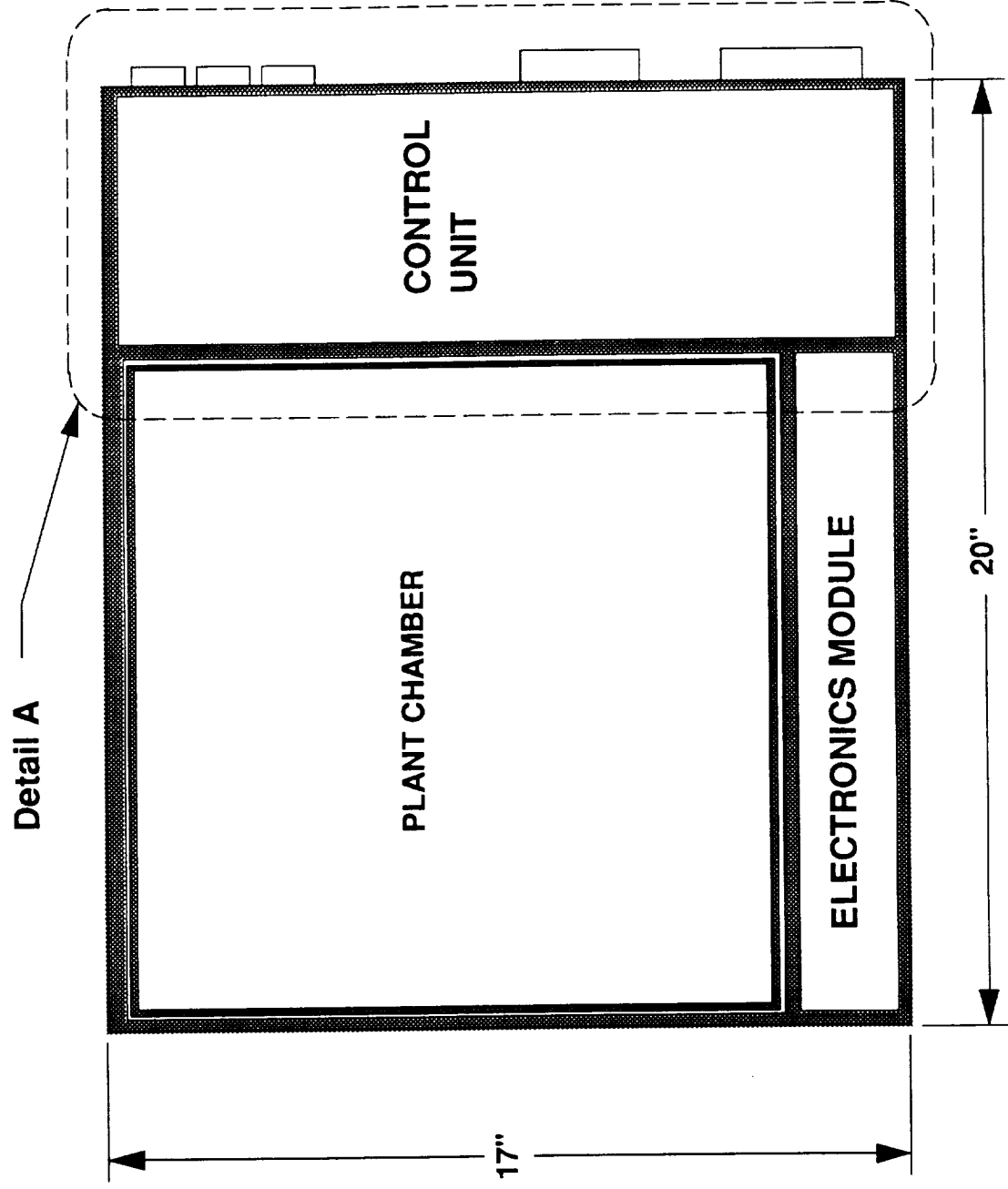
ELECTRICAL BLOCK DIAGRAM



DESIGN DESCRIPTION (CONT'D)

The illustration shown on the facing page is a plan view of the Plant Habitat. This view shows the 3 functional zones within the habitat. A detailed view of the aft end of the plant habitat is shown on the following pages followed by two section views of the control unit (detail A). These views illustrate the packaging involved for the control unit of the Plant Habitat. For clarity, the plumbing for the nutrient delivery system and gas supply system is not shown. Sizing of components is based on available hardware wherever possible.

PLANT HABITAT PLAN VIEW

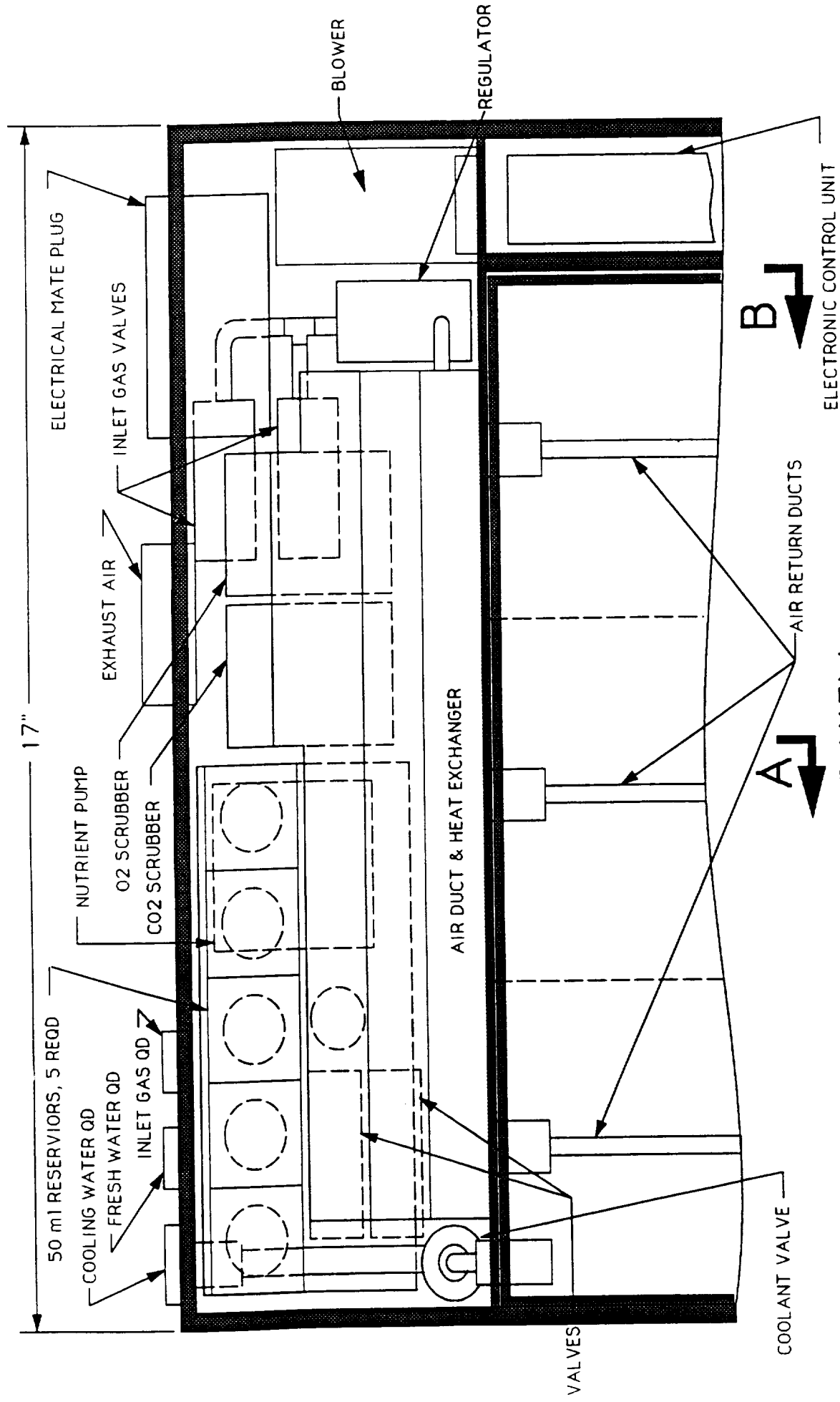


DESIGN DESCRIPTION (CONT'D)

Detail A shows the general layout of the control equipment for the Plant Habitat. The nutrient reservoirs and other related nutrient delivery equipment have been packaged together. Equipment for the gas supply adjustments has been packaged on the right of the habitat. This packaging arrangement was chosen to efficiently package similar items as close together as possible to reduce the amount of plumbing needed. However, it was desirable to separate the fluid related components from the electronics module to reduce the risk of electrical shorts.

As shown in these views, the packaging density is high.

PLANT HABITAT TOP VIEW

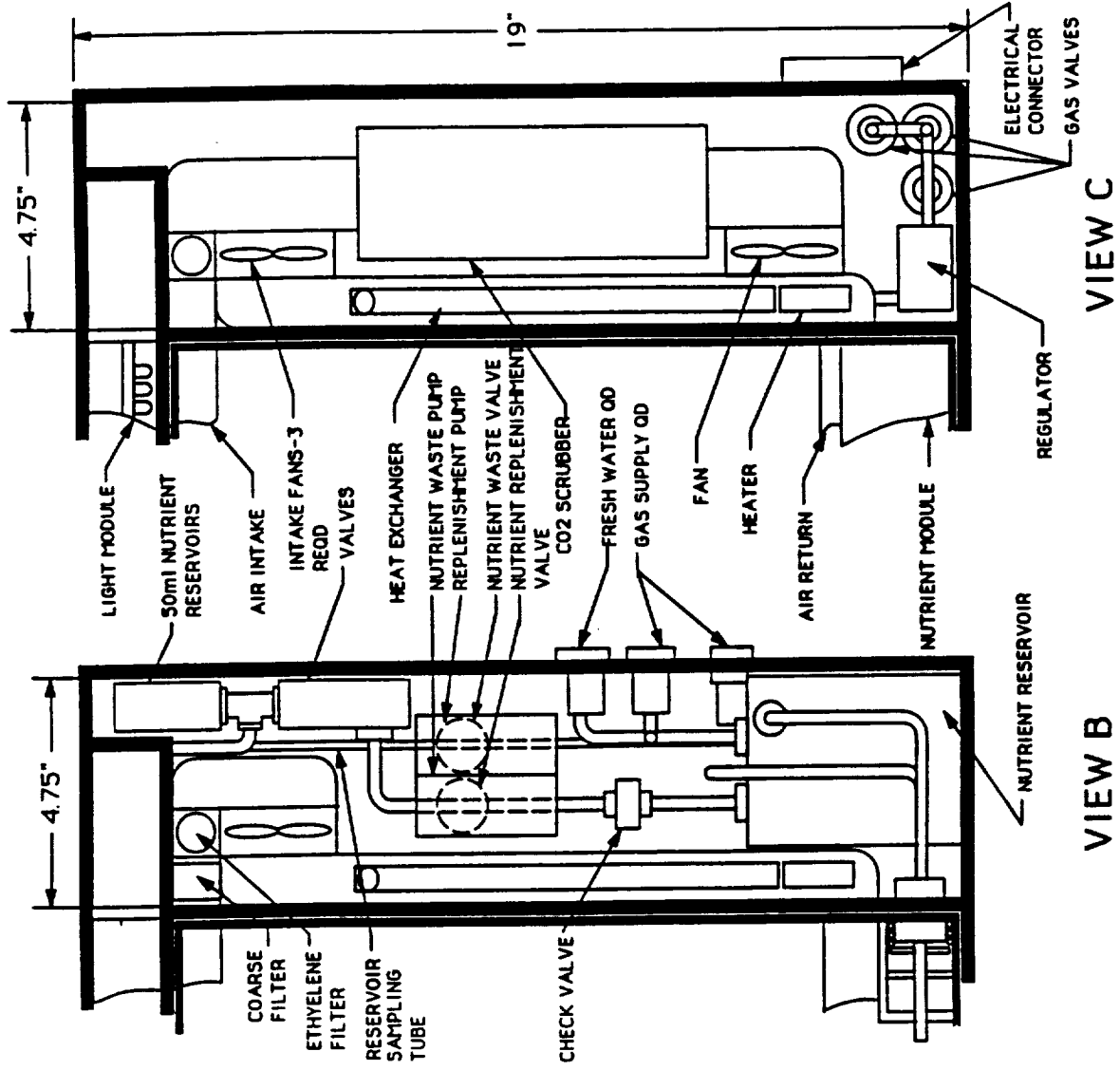


TOP VIEW
PLANT HABITAT SUPPLY UNIT

DESIGN DESCRIPTION (CONT'D)

Views B and C shown on the facing page are section views of the rear of the Plant Habitat. View B shows the packaging arrangement of the nutrient system. View C shows the packaging arrangement of the atmosphere adjustment and recirculating system.

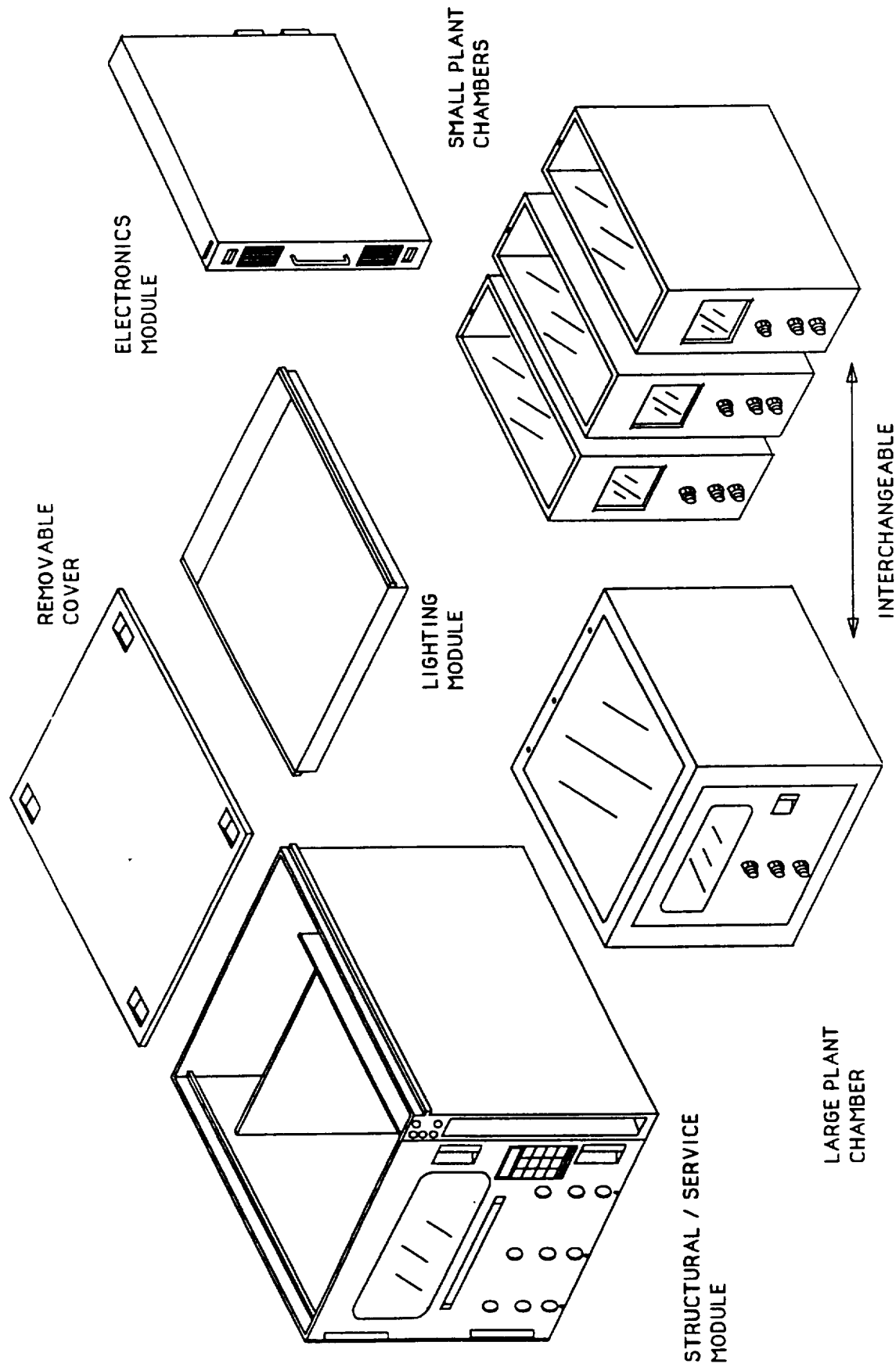
PLANT HABITAT SECTION VIEW



HABITAT CHARACTERISTICS

As shown on the facing page, the Plant Habitat can be separated into several functional units. This will enable various units such as the electronics module to be removed for repair or replacement. The top of the habitat is equipped with a removable cover to allow removal of the plant chambers and lighting module from the habitat. The plant chambers can also be removed from the front of the habitat. The service module will house all of the pumps, fans, nutrient reservoirs, heat exchangers, ducts, and tubing.

PLANT HABITAT FUNCTIONAL UNITS



HABITAT CHARACTERISTICS (CONT'D)

The large plant chamber can accommodate three, 8.9 cm wide x 33 cm long (3.5" x 13") modular nutrient trays. The tray depths may vary according to plant root requirements and the tray position relative to the lighting module can be adjusted according to experiment requirements. These adjustments are accommodated in the plant chamber by positioning holes and slides at three heights along the chamber walls.

All interior surfaces of the plant chamber are reflective. The top of the plant chamber is made of clear Lexan to permit light to enter the chamber from the lighting module. The front door of the plant chamber has an observation window. This window can be covered by a filter or an opaque shield to block light from the cabin. Similar filters can be placed over the Lexan window on top of the plant chamber.

Airflow is directed into the plant chamber from four air inlet ducts. The ducts act as partitions and supports for the nutrient trays. Two of the ducts are positioned against the walls of the habitat to reduce the possibility of dead air space in the corners of the habitat. Vanes located on the top of the ducts distribute air uniformly through the habitat. The ducts can be outfitted with extension sleeves with sliders to accommodate nutrient trays located at higher positions. Three air return ducts are located on the ceiling of the habitat. The cross section of the ducts are thin so that light from the lighting module is not obstructed. The openings in both the air inlet and return ducts are designed to maintain a balanced airflow along the length of the ducts. Furthermore, the total area for the air inlet opening is equal to the total area of the air outlet opening to maintain airflow uniformity within the plant chamber.

Quick-disconnects (QD's) connect flexible tubing on the nutrient trays to the nutrient delivery system. These are retractable to allow the plant chamber to be unfastened from the Plant Habitat and removed from either the front or the top of the habitat. A rod running from the front to the rear of the habitat allows the QD's to be screwed into position with the aid of a retractable key handle. To release the QD's, a quarter turn pin located on the top and front of the habitat can be depressed and rotated to disengage the QD's. The QD's, which are spring-loaded, are mounted on the inner wall of the habitat.

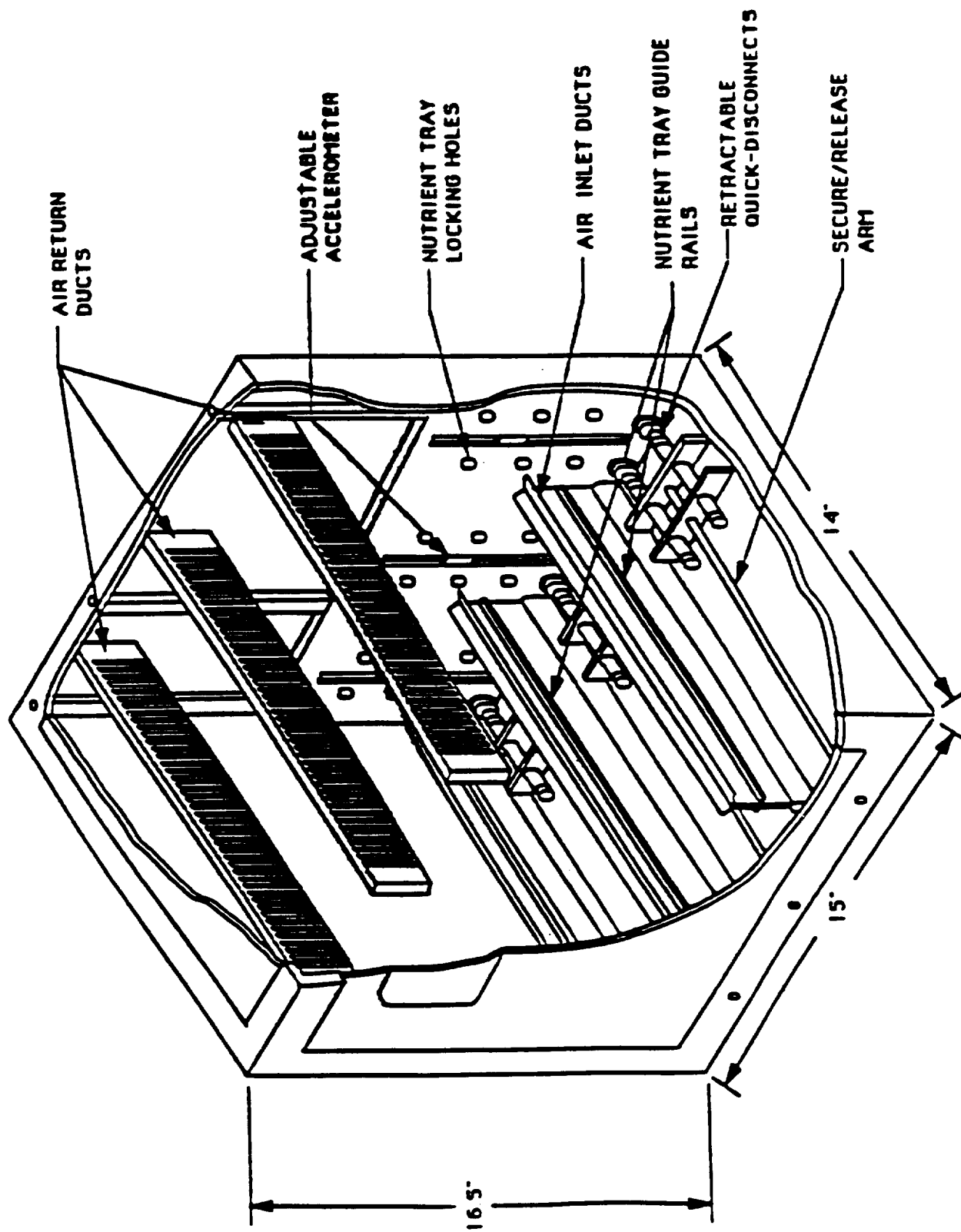
LARGE PLANT CHAMBER DESCRIPTION

- Accommodates three nutrient trays 8.9 cm wide x 33 cm long (3.5" x 13")
- Three heights for nutrient trays to adjust root/shoot boundaries
- Highly reflective surfaces for light distribution.
- Accelerometer can be positioned at different root/shoot zone heights
- Air inlet ducts can be fitted with extension sleeves for elevated nutrient trays
- Openings sized to promote uniform air flow
- Retractable quick-disconnects.

HABITAT CHARACTERISTICS (CONT'D)

The cutaway isometric view on the facing page illustrates the components within the large plant chamber.

LARGE PLANT CHAMBER



HABITAT CHARACTERISTICS (CONT'D)

The small plant chamber affords the option of removing one set of plant specimens from the Plant Habitat without disturbing plant specimens in adjacent specimen chambers. The small plant chamber is similar to the large plant chamber and one third as wide. The small plant chamber is outfitted with two air inlet ducts along the side walls and one air return duct located in the center of the ceiling. As with the large plant chamber, the small plant chamber can be removed from either the top or front of the Plant Habitat.

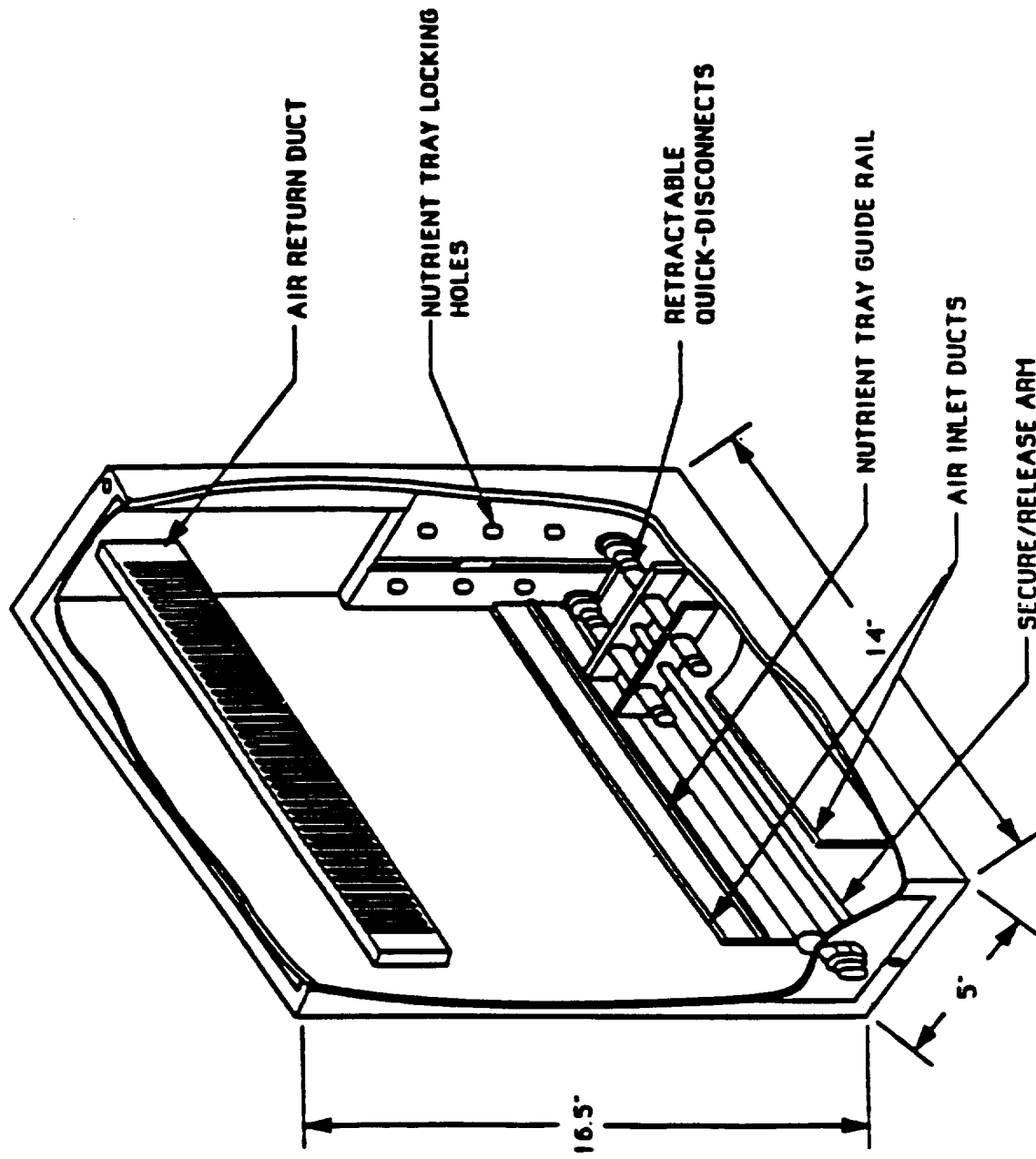
SMALL PLANT CHAMBER DESCRIPTION

- Can accommodate 8.9 cm wide x 33 cm long (3.5" x 13") nutrient tray
- Small chamber has all the features of the large chamber
- Up to three small chambers fit in the Plant Habitat
- Two air inlet ducts are positioned at the sides of the chamber. Diffusers located at air exit points can direct and distribute air flow

HABITAT CHARACTERISTICS (CONT'D)

The cutaway isometric view on the facing page illustrates the components within the small plant chamber.

SMALL PLANT CHAMBER



HABITAT CHARACTERISTICS (CONT'D)

The nutrient tray supports a solid matrix with a continuous flow of nutrient solution and hydroponics hardware. Both hydroponics and solid matrix are used for the baseline design of the nutrient tray. The membrane located on top of the nutrient tray depends on the type of nutrient delivery. This membrane supports the plants and provides a barrier between the plant root and shoot zones. The tray top is lined with a gasket to maintain a water tight seal.

One potential problem may be the entanglement and damage of plant canopies when one tray is removed.

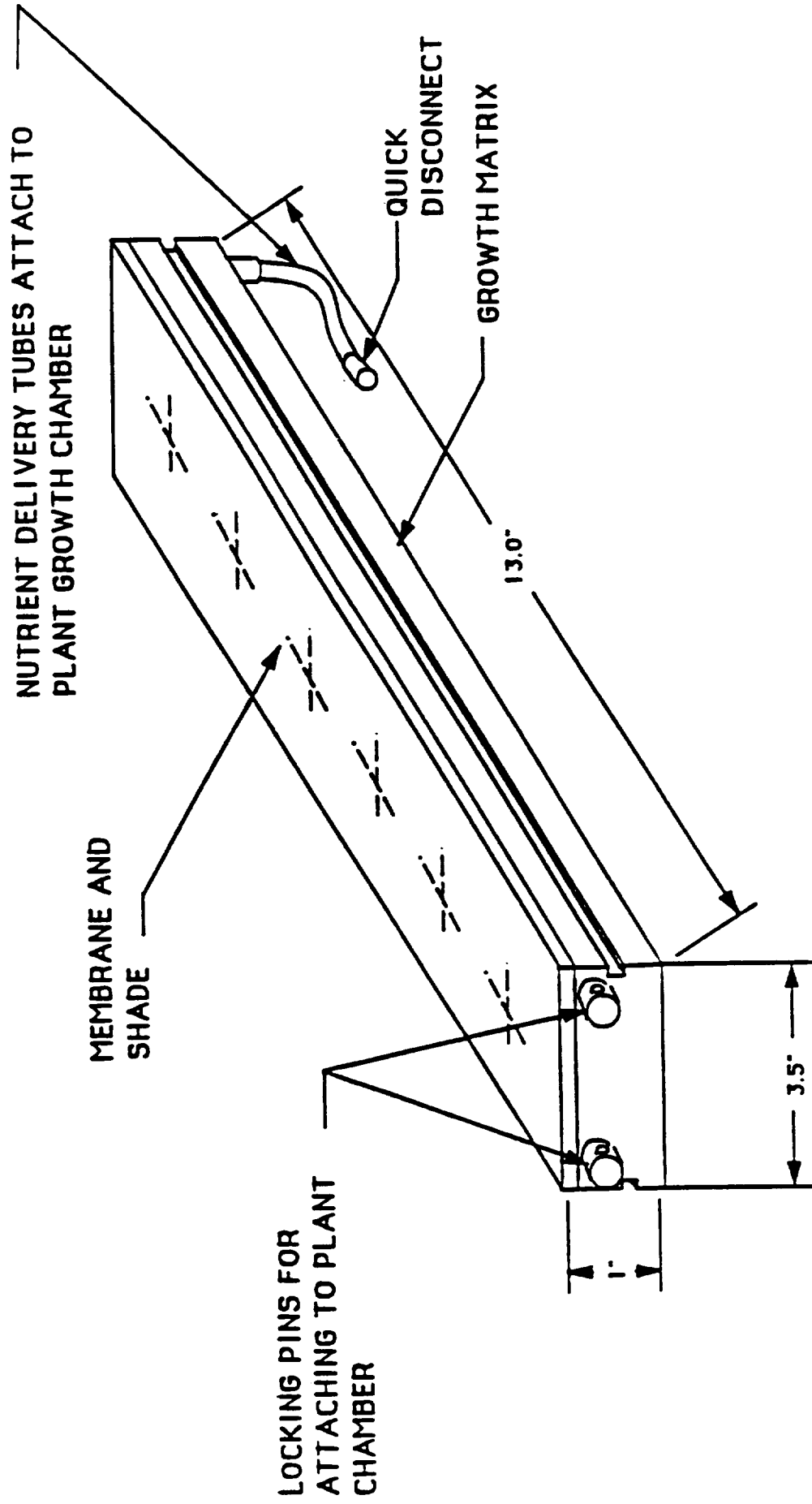
NUTRIENT TRAY DESCRIPTION

- Trays measure 8.9 cm wide x 33 cm long (3.5" x 13") depth from 2.5 cm to 15 cm (1" to 6")
- Baseline design of the tray supports hydroponics and growth matrix
- Commonality of trays are as follows:
 - Size of tray
 - Mounting surfaces
 - Quick disconnects for nutrient supply and return
- Types of nutrient delivery possible
 - Solid matrix with continuous flow of nutrient solution
 - Hydroponic

HABITAT CHARACTERISTICS (CONT'D)

Two nutrient tray depths, 2.5 cm and 7.5 cm, (1", 3"), are provided in the baseline design. All trays are interchangeable between the large and small plant chambers. Guides are provided on both sides of the tray to position it within the plant chamber. Ball-lock pins, located on the aft end of the tray, secure the tray to a mounting plate in the aft end of the plant chamber. Flexible lines located on the bottom of the tray connect to a waste water removal system via quick-disconnects on the plant chamber. The flexible tubing permits easy installation of the nutrient tray. Moreover, the flexible tubing permits vertical relocation of the tray without the need of additional fittings.

NUTRIENT TRAY



HABITAT CHARACTERISTICS (CONT'D)

The lighting module supplies a specified amount of light over a spectrum matching the needs of a particular plant experiment. Video hardware located in the rear of the module allows the experimenter back on earth to orthogonally view, monitor, and record progress of the experiment.

Guide rails along the lighting and video module allow it to slide in and out from the front of the habitat when the habitat cover is removed.

The module uses an LED array to supply the required photon flux up to a total of 600 $\mu\text{mole/m}^2/\text{s}$. Most of this energy will be provided in the range of 660-670 nm, while 10 $\mu\text{mole/m}^2/\text{s}$ will be supplied between 400-500 nm. The LED array will have LEDs operating at specific wavelengths to stimulate accessory pigments within the plant such as phycocyanin, phycoerythrin, and carotene. Since the lighting needs of plants can vary from one species to another, custom LED arrays can be fabricated and easily swapped with the baseline LED array. Each custom array can fasten to the framework of the lighting module. These custom arrays can match a plant's specific demand for light intensity and wavelength. Current estimates show that approximately 400 LEDs drawing a total of 40 watts would meet the requirements.

Video hardware in the rear of the light module can transmit color or infra-red video signals; color transmissions can be converted to black and white at the receiving end. One color and one infra-red video camera lens are mounted on a motorized track. The motorized track serves two purposes. First, it changes the viewing angles in the large plant habitat. Second, it permits observation into each of the small habitats. Fiber optic tubing joins the camera lens to the video hardware console.

LIGHTING MODULE

Lighting:

- LED array supplies a maximum of 600 $\mu\text{mole/m}^2/\text{s}$ in a spectrum of 660-670 nm and 10 $\mu\text{mole/m}^2/\text{s}$ in a spectrum of 400-500 nm. Additional LEDs supply energy at wavelengths needed to stimulate accessory pigments such as phycocyanin, phycoerythrin, and carotene
- Estimate 400 LEDs required. The lighting module will draw approximately 40 watts; each LED requires 100 mW
- Lighting modules can be designed to meet spectral requirements of specific plant experiments

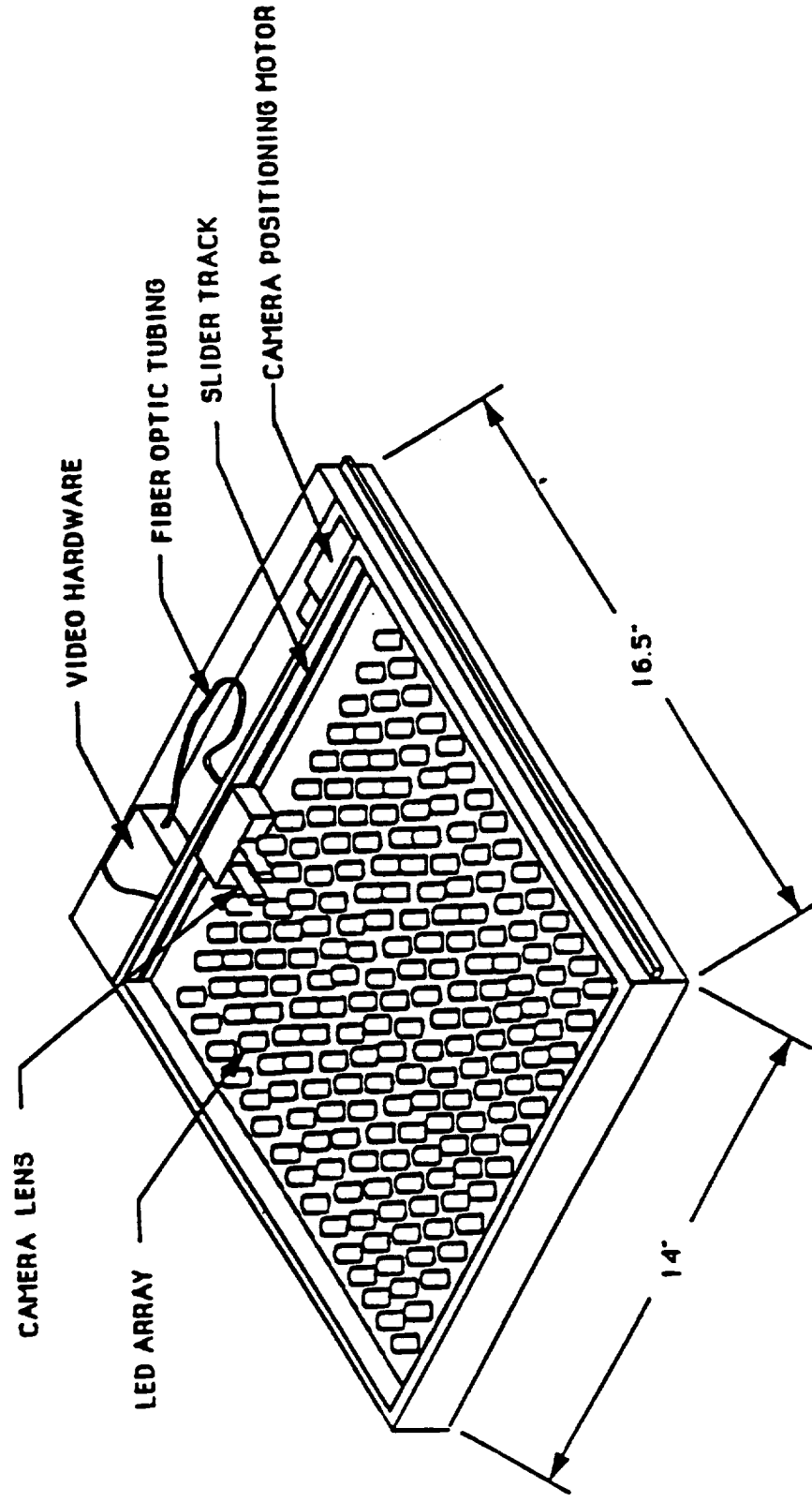
Video:

- Color and infrared capability
- Camera lens is positioned using slider track and positioning motor
- Fiber optics allow video hardware to remain stationary while camera lens moves to desired location
- Video hardware similar to Rodent and Primate Habitat video hardware

HABITAT CHARACTERISTICS (CONT'D)

An isometric view of the Lighting and Video Module is shown on the facing page. This view shows the approximate location and configuration of the video hardware and LED array.

LIGHTING MODULE



HABITAT CHARACTERISTICS (CONT'D)

Electronics which control variables in the Plant Habitat are consolidated in an electronics module. This module contains all logic circuits to control variables including: atmospheric composition (temperature, humidity, and air flow rate regulation); nutrient composition (pH, oxygenation, temperature, and flow rate); lighting and video. Commands can be transmitted to the electronics module either directly from the input keypad located on the front door of the habitat or remotely from the Holding System, Centrifuge, or Glovebox control panels or from a data input center located on the Space Station or on Earth. The electronics module will also transmit science and engineering data from the habitat to the Space Station to be recorded or transmitted to Earth.

A description of the various components from which the module is comprised is provided following the facing page.

ELECTRONICS MODULE DESCRIPTION

- Contains all logic circuits for environmental control, power conditioner, and battery backup for memory maintenance.
- Air ducts at rear of electronics module mate with blower in habitat service module
- Vents in front of electronics module have a grill which prevents blockage from loose debris floating in cabin
- Locking tabs and retractable handle permit easy module removal for servicing
- Cabin air is used to cool the electronics module
- Coarse filters trap lint and metallic particles

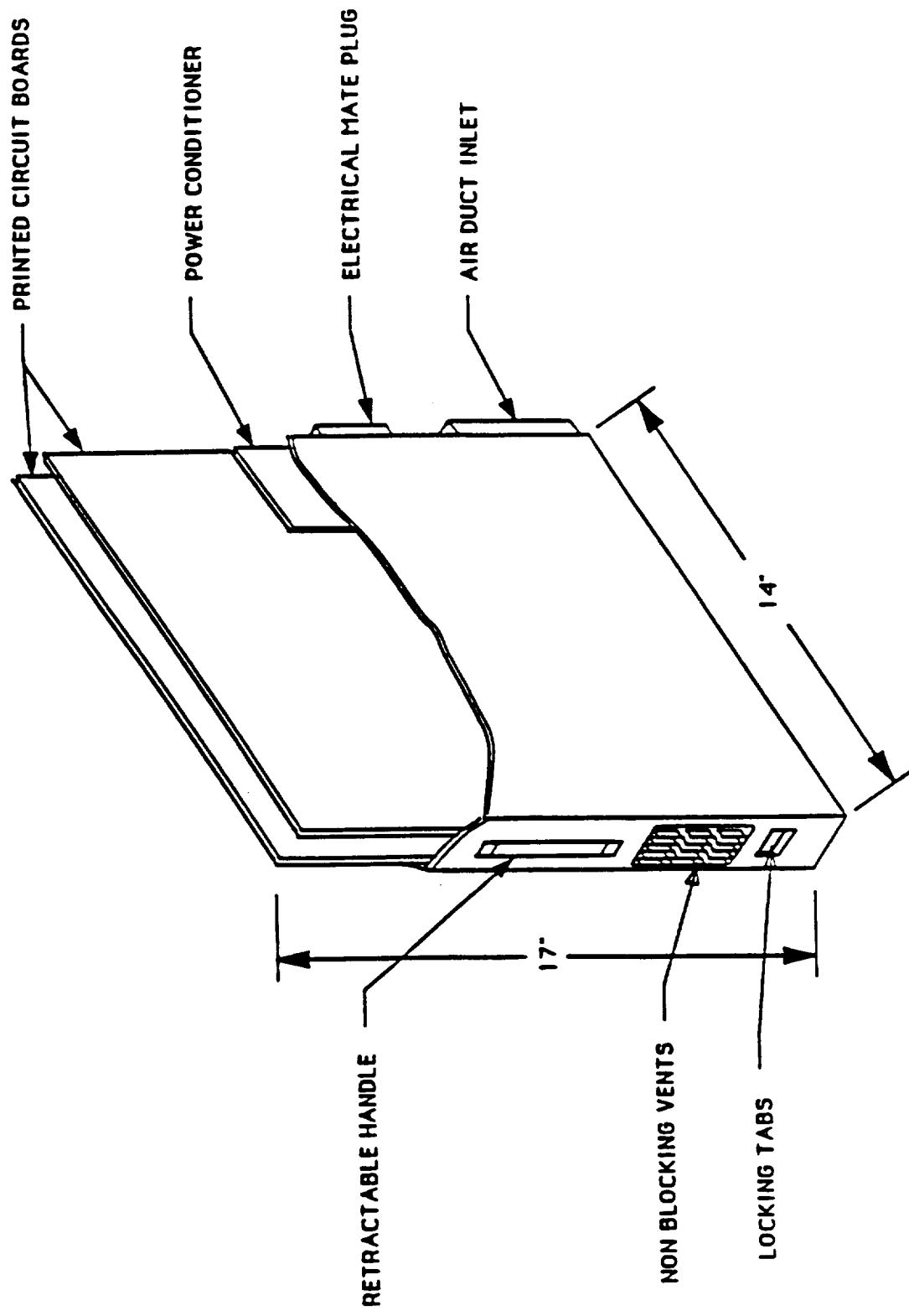
HABITAT CHARACTERISTICS (CONT'D)

The electronics module shown on the facing page consists of two custom PC boards and a power conditioner to monitor and control the environment within the plant habitat. The electronics module measures 43cm high x 6cm wide x 36cm deep (17" x 2.5" x 14"). The unit is designed to be easily inserted or removed from the front of the habitat. Locking tabs fasten the module to the service module.

An electrical connector at the rear of the module provides the interface for signals from the habitat control hardware and sensors at the rear of the habitat.

Two "non blocking" vents are located in the front of the habitat to allow cabin air to circulate through the electronics module for cooling. The "nonblocking vents" are louvers that prevent material such as paper from obstructing air flow. Coarse filters are provided to prevent lint or metallic particles from entering the module. The blower, used to circulate air through the electronics module, is part of the of the structural/service module and connects to air inlet and outlet ducts at the rear of the electronics module.

ELECTRONICS MODULE



HABITAT CHARACTERISTICS (CONT'D)

The table shown on the facing page lists weight and volume estimates for the Plant Habitat . The individual component estimates are based on engineering judgment, catalogue values, and calculations (abbreviated under the Basis column as Rough, Cat, or Calc respectively). For "off the shelf," components weights and volumes were based on catalog specifications. The weight of the shell structure of the habitat is based on the use of aluminum members.

Volume estimates show that the volume available has been almost entirely used. Miniaturization of components and technology development in other areas, such as CO₂ scrubbers, may alleviate some of the problems encountered in this concept design. With the volume estimates so close to the habitat capacity, a great deal of attention will need to be given to the priorities and amounts of equipment to be packaged within the volume available

PLANT HABITAT MASS/VOL. ESTIMATE

| SUBSYSTEM & COMPONENTS | | Mass | Volume | Basis for value |
|---|--|------------|------------------------------------|-----------------|
| Consumables | | kg (lb) | cm ³ (in ³) | |
| -750 ml Nutrient Reservoir | | 3.6 (8) | 4231 (258) | Calc |
| -5 - 50 ml Nutrient Reservoirs | | | | |
| -Ethylene, CO ₂ , & O ₂ scrubbers | | | | |
| -Air filters | | | | |
| Electronics module | | 6.8 (15) | 7806 (476) | Rough |
| Lighting module | | 4.5 (10) | 7511 (460) | Rough |
| Powered mechanisms | | 11.3 (25) | 19709 (1201) | Rough |
| -pumps - 3 reqd | | .9 (2) | | |
| -fans - 6 reqd | | .9 (2) | | |
| -solenoid valves - 15 reqd | | 2.1 (5) | | |
| -video camera | | .9 (2) | | |
| -plumbing, ducts, and cables | | 6.3 (14) | | |
| Shell structure & cover | | 13.6 (30) | 9873 (602) | Rough |
| Plant growing chamber | | 3.6 (8) | 50840 (3100) | Rough |
| Total mass | | 43.6 (96) | | |
| Plant Habitat envelope | | | 105944 (6460) | Rough |
| Percent of total volume | | | 94% | |
| 25% Design contingency | | 10.9 (24) | | |
| TOTAL | | 54.5 (120) | | |

HABITAT CHARACTERISTICS (CONT'D)

The table on the facing page lists power estimates required to operate the Plant Habitat. The column for average power lists the power estimates for conducting a plant growth experiment with lights operating at 400-500 $\mu\text{mole/m}^2/\text{s}$ for a 24 hour photoperiod (most experiments may only require an 8-12 hour photoperiod which lowers the average power requirement.)

The peak power column lists the maximum amount of power required for experiments in which all components are activated at the same time. Under normal operations, peak power levels would be substantially less.

Most of the heat generated by the plant habitat will be from the lighting and electronics module. Thermal energy generated from the lighting module will be absorbed by a heat exchanger and transferred to the coolant loop. The electronics module will reject heat directly to the cabin by means of forced convection.

PLANT HABITAT POWER ESTIMATES

| | Average power (watts) | Peak power (watts) | Source of heat Rejection |
|----------------------------|--------------------------|-----------------------|-----------------------------|
| Electronics module | 45 | 50 | cabin air |
| Sensors (13) | 2 | 2 | coolant loop |
| Lighting module | 80 | 100 | coolant loop |
| fans (5) | 24 | 40 | coolant loop |
| blower | 15 | 17 | cabin air |
| pumps (3) | 5 | 15 | coolant loop |
| Solenoid valves (15) | 6 | 30 | cabin air |
| Video camera & drive motor | 3 | 12 | cabin air |
| Heaters (2) | 5 | 40 | coolant loop |
| Total power | 185 | 306 | |

Average level heat rejection into coolant loop - 116 watts

Average level heat rejection into cabin air - 69 watts

Note: Power for lighting is based on 40w for LEDs and 40w for blue light florescent. An additional 400w would be required if florescent bulbs were substituted for LEDs

HABITAT CHARACTERISTICS (CONT'D)

The data rates listed on the facing page represent normal transmission rates for the Plant Habitat. These rates could be substantially higher if vibration levels were to be continuously monitored and transmitted. Overall, these data rates are low as compared to the data rates for the animal habitats. Typical plant science data would be nutrient pH, conductivity, temperature and humidity measurements.

PLANT HABITAT DATA

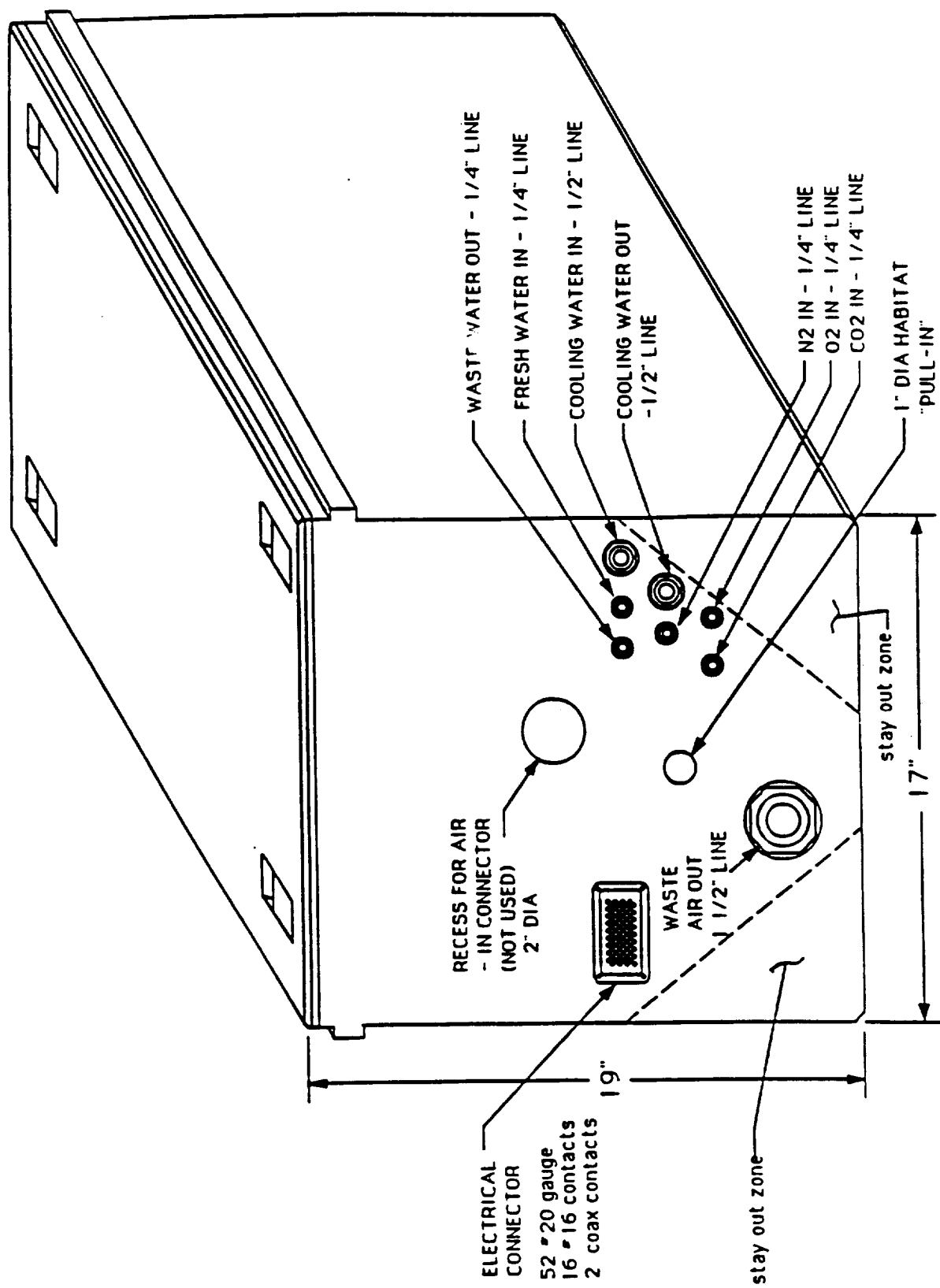
| Data type | Data Rates (BPS) |
|--------------------------|------------------|
| Engineering data | 270 |
| Science data | 200 |
| Total data | 470 |
| Internal video channels* | 1 |

* One video camera will be equipped with one color lens and one infrared lens

EXTERNAL INTERFACES

The aft end of the Plant Habitat connects to the standard interface plate located on the Holding System, Centrifuge and Glovebox. Quick-disconnects couple to lines which supply gases, water, and cooling water to the habitat and reject waste water, and waste air. Unlike the Rodent and Primate Habitats, the Plant Habitat does not use Freedom cabin air. The Plant Habitat relies on the supply of individual gases for atmospheric control.

EXTERNAL INTERFACES



TRADEOFFS

A number of top level tradeoffs were conducted at the beginning of the study to help define a design which can meet science requirements within the available habitat volume. An outline of these tradeoffs is listed on the facing page. Results of the tradeoffs are summarized on subsequent pages.

TRADEOFFS OUTLINE

Plant Habitat tradeoffs made during this study

- Type of light source
- Serviceability vs size and complexity
- Video systems
- Diagnostic capability

TRADEOFFS

The table on the facing page summarizes a tradeoff between lighting techniques for the Plant Habitat. The type of lighting selected is critical to the success of the Plant Habitat as a scientific test bed. Two of the three light options represent sources currently used in the plant growing community.

High Intensity Discharge lamps produce high photon flux levels. They are impractical for Plant Habitat use due to the high heat output which cannot be rejected with low air flow rates. This is a result of their low overall efficiency of converting power to usable light.

Fluorescent bulbs are widely used for plant growth experiments. Unfortunately, a number of drawbacks exist with fluorescent bulbs which reduce their effectiveness for plant growth experiments in space. The main drawback is the limitation to a maximum photon flux of 350-450 $\mu\text{moles}/\text{m}^2/\text{s}$. Furthermore, the intensity of the lamps decreases proportionally with the length of the tube (a 46cm lamp cannot operate as efficiently as a 1m lamp). Also, fluorescent bulbs used in space require a safety sleeve, usually made of Teflon, which further limits their output. Calculations show that fluorescent lighting for the habitat would require approximately 480 watts. Approximately 160 watts of this would enter the plant chamber as thermal radiation. The ability to reject this heat is difficult at 0-10 air changes per hour. Furthermore, the increased heat loads within the plant chamber would increase plant transpiration rates, thus making it more difficult to control humidity levels.

Significant advances have made LED technology promising as a light source for plant growth in space. Recent tests using LED arrays have demonstrated that photon flux levels of 500-600 $\mu\text{moles}/\text{m}^2/\text{s}$ are attainable while using a fraction of the power needed for fluorescent bulbs. This is accomplished by delivering to the plant, energy at wavelengths that plants most efficiently absorb and by directing the light more efficiently than fluorescent bulbs. Because LEDs are available in 20 nm bandwidths over a range of 550-700 nm, custom arrays can be constructed for specific plant species. The thermal load into the plant chamber is estimated to be no more than 40 watts. The lower levels of heat rejection would be compatible with low air change rates and would not cause an increase in the plant transpiration rates.

LEDs operating in the blue light spectrum are in the early stages of development. Output levels of blue light LEDs is lower than desired. One alternative to this may be to include two, 20 watt blue phosphor fluorescent lamps in the habitat to make up for this deficiency.

LIGHTING

| Fluorescent | Light Emitting Diode | High Intensity Discharge |
|---|--|--|
| <ul style="list-style-type: none"> + Uniform light distribution - Max photon flux attainable is 350-450 $\mu\text{mole/m}^2/\text{s}$ + Produces light in a broad spectrum - Requires shielding of tubes which lowers efficiency - Heat output moderate - Output drops to approximately 50% after 10,000 hours | <ul style="list-style-type: none"> + Uniform light distribution + Photon flux levels of 500-600 $\mu\text{mole/m}^2$ easily attainable, 1000 $\mu\text{mole/m}^2$ possible - Produces light in narrow spectrum + Requires no shielding + Heat output low + Output consistent over 100,000 hour life + Can tailor spectral content with specific plant experiments | <ul style="list-style-type: none"> - Point source distribution + Photon flux levels over 1000 $\mu\text{mole/m}^2$ possible + Produces light in a broad spectrum - Requires shielding of tubes which lowers efficiency - Heat output high + Output consistent over 10,000 hour life |

Current Choice: LEDs appear to be the most promising light source, however blue light LEDs need further development. If necessary, blue phosphor fluorescent bulbs can supplement LED arrays

TRADEOFFS (CONT'D)

The table on the facing page summarizes a tradeoff between a fully modular plant habitat and an integrated habitat which affects the serviceability and complexity of the habitat. One of the design goals of this study was to design the habitat for easy serviceability. One method of accomplishing this is to divide the habitat into modular components. However, with the limited volume associated with the habitat, modularity can only be accomplished to a certain point before it becomes self defeating.

It was decided to design an electronics module that would consolidate all the electronics within the habitat. This facilitates the replacement of faulty electronics with a new module. The lighting/video module is configured such that LED arrays could be selected to match the needs of individual plant experiments.

The nutrient and gas delivery systems are designed as part of the habitat and are not modular. Originally, these systems were to be removable or replaceable modules. However, the reduction in volume associated with the use of quick-disconnects reduced the merits of designing modular systems. Furthermore, additional QD's increase the likelihood of leakage in the system, another disadvantage of modularity.

As shown in the block on the facing page, the current choice still provides some modularity, but without the volume reduction for the QD's. Servicing the current system would be cumbersome and habitat repairs might need to be performed on the ground.

MODULARITY VS USEABLE VOLUME

| Fully modular construction | limited use of serviceable modules |
|---|---|
| <ul style="list-style-type: none"> + Most components can be replaced or repaired easily - Increased quantity of Quick Disconnects increase possibility of leakage - Size of plant chamber would be reduced substantially - Available volume for control systems substantially reduced | <ul style="list-style-type: none"> - Some components cannot be replaced or repaired easily. + Reduced number of fluid connections reduce chance of fluid leakage + More efficient packaging of components increases size of plant chamber + More efficient packaging of components increases the number of control system locations |

Current Choice: Limit modularity to increase the size of the plant growth chamber. Keep electronics and lighting modular, to reduce down time of the Plant Habitat

TRADEOFFS (CONT'D)

A tradeoff was performed to determine whether or not more than one video camera should be provided in the Plant Habitat to enable viewing from a horizontal position; viewing from a horizontal position would give a better visual record of plant growth within the chamber. This is desired but not required. At this time, provisions for one video camera on a motorized track have been made since volume constraints increase the difficulty in providing a second camera. Continued efforts will be made to research the possibility of adding a second camera or a means of obtaining the orthogonal view.

ONE AXIS VS TWO AXIS VIDEO

| Two axis video system | One axis video system |
|---|---|
| <ul style="list-style-type: none"> + Two axis viewing can show top and side views - Increased camera electronics require more volume - Increased complexity - Side mounted cameras compete with air ducts and heat exchanger for volume | <ul style="list-style-type: none"> - Video limited to overhead viewing unless an optic arrangement is included + Minimal camera electronics + Minimal complexity + No impact on ducting or heat exchanger |

Current Choice: A single axis camera to provide viewing from the top of the chamber. A motorized slider in the lighting module positions the camera along the top rear of the plant chamber.

TRADEOFFS (CONT'D)

The table on the facing page summarizes a tradeoff to determine the level of diagnostic capability in the Plant Habitat. This study examined the balance between the level of diagnostic capability and system accommodation impacts including complexity and volume. The approach selected was to implement a partial diagnostic capability which would detect system level failures only.

DIAGNOSTIC CAPABILITY

| Full diagnostic capability | Partial diagnostic capability |
|--|---|
| <ul style="list-style-type: none"> + Able to detect and pinpoint component failure - Addition of more sensors takes more volume than available - Increased complexity - Additional volume required in electronics module | <ul style="list-style-type: none"> - Able to detect a system failure but not a component failure + Limited number of sensors fit within allocated volume + Minimal complexity + No additional volume required in electronics module |

Current Choice: Use limited diagnostic capability, since it is difficult to repair most control system components, thus limiting the benefits of full diagnostic capability.

OPERATIONAL SUMMARY

The user of the Plant Habitat has two options for transporting plant specimens to the Glovebox. The user could take the entire Plant Habitat out of the Holding Unit or Centrifuge and transport it to the Glovebox or leave the habitat in the parent system while removing and transporting only the plant chamber. One possible method of transporting an individual plant chamber is shown later. In this method, a flexible transport bag would be used to maintain bioisolation.

Another operation for Plant Habitat maintenance is nutrient replenishment. This should only be necessary for long duration experiments. Since the refilling ports for the nutrient solution are located in the front of the habitat, this operation can be performed without removing the Plant Habitat from the Holding Unit. Precautions for handling fluids such as acids and bases would be observed.

The electronics module could be removed for servicing while the habitat is in the rack. This should only be necessary for malfunctions in the electronics module. The lighting module can be removed from the top of the habitat when the habitat is connected to the Glovebox to allow removal of the plant chamber.

OPERATIONAL SUMMARY

- Plant chambers can be removed from front of Plant Habitat without removing habitat from Holding Unit. Plant chambers can be transferred to the Service Unit for cleaning or to the Glovebox using orbital support equipment to maintain bioisolation
- Plant Habitats transferred from the Holding Unit and connected to the Glovebox. Plant chambers removed vertically from the top of the Plant Habitat into the Glove box
- Nutrient solutions replenished periodically based on plant. Replenishment accomplished through ports at front of habitat
- Gas and nutrient sampling through ports in front of habitat performed as required
- Serviceable and replaceable light and electronics modules to reduce down time of habitat

OPERATIONAL SUMMARY (CONT'D)

Under most conditions, the gas scrubbing cartridges contained within the habitat would not have to be exchanged over the duration of the experiment. An exception to this is for experiments running at low O₂ levels. The O₂ scrubber for experiments requiring O₂ concentrations of 5% may only last for three to four days before needing replacement. Since all the gas scrubbers are located in the rear of the Plant Habitat, servicing would need to be accomplished on a work bench. The gas scrubber cartridges are accessible by removing the top cover of the habitat. The air filter and ethylene filter are serviced in the same manner as the scrubbers.

OPERATIONAL SUMMARY (CONT'D)

- Cartridges for scrubbing gases need to be exchanged as follows:

Ethylene and CO₂ cartridges to be exchanged every 2-3 months

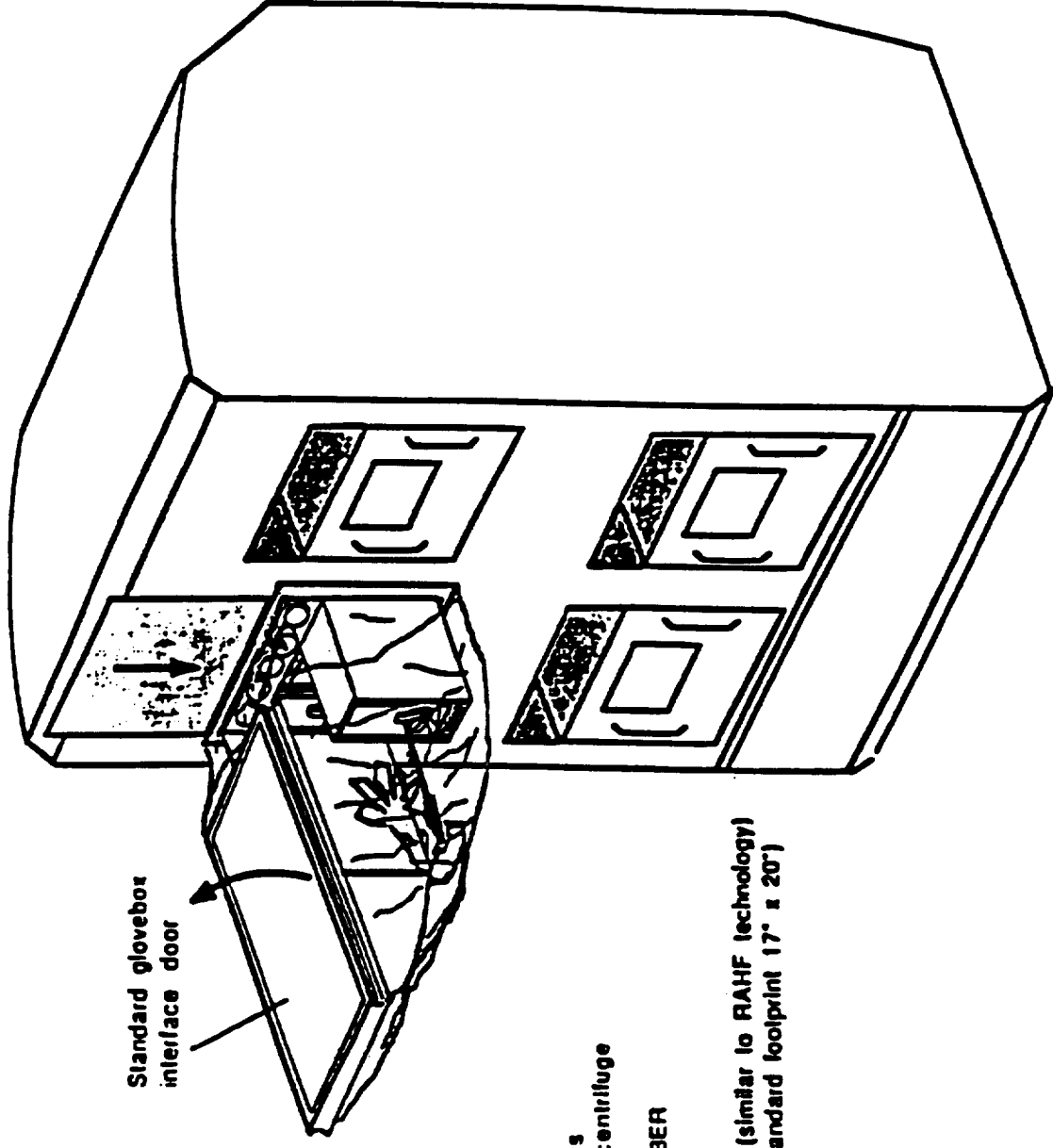
O₂ cartridges to be exchanged every 2-3 months for experiments operating with O₂ concentrations above 20%

O₂ cartridges to be exchanged every 3-4 days when growing mature plants at O₂ concentrations of 5%

OPERATIONAL SUMMARY (CONT'D)

The drawing on the facing page shows the transfer of a small plant chamber from the Holding System to the Glovebox. The transfer is made with the aid of a transport bag to maintain bioisolation.

PLANT CHAMBER TRANSFER



Transport Bag for transfers
between holding system/centrifuge
and glovebox for
PARTITIONED PLANT CHAMBER

- flexible transport bag
- one door to holding slot (similar to RAHF technology)
- one door to glovebox (standard footprint 17" x 20")

REQUIREMENTS NOT MET

Requirements not met in the current design concept include maintaining O₂ concentrations of 5% for the required mission duration and maintaining temperature uniformity to $\pm 1^{\circ}\text{C}$ at 1-10 air changes per hour. There may be an acceptable solution to running plant experiments at low O₂ levels. If the volume dedicated for one small plant chamber were used to house an additional O₂ scrubber, then it may be possible to meet the requirement.

There are conditions when it is not possible to meet the requirements for air temperature uniformity. One example is when lighting is provided at or near full intensity while air flow is near the lower limit of its range. This is due to a lack of heat transfer by convection in micro-gravity. Further analysis and testing is necessary to better evaluate this problem.

REQUIREMENTS NOT MET

The following requirements have not been met by the current concept:

- O₂ concentrations of 5% cannot be maintained for more than 4 days per habitat without replenishment while the Plant Habitat is on the Centrifuge
- Temperature uniformity appears difficult to maintain to within $\pm 1^{\circ}\text{C}$ given an air change rate of 1-10 air changes per hour

TECHNOLOGY DEVELOPMENT

Experimental evidence suggests that various environmental stresses, including mechanical vibration, affect the growth patterns of plants. It is theorized that plants will have an increased sensitivity to vibration/accelerations in a micro-gravity environment. A test plan is being developed at ARC to determine vibration sensitivity levels of plants.

Further work needs to be done in developing a compact and reliable condensing heat exchanger and air/water separator. New designs being developed look promising for use in the Plant Habitat.

Studies for lighting modules which are energy efficient and provide the required intensity and wavelength are needed. Furthermore, a camera arrangement which can provide side viewing of the plants needs to be studied.

Current methods of scrubbing excess oxygen rely on chemical reactions which absorb oxygen in an exothermic reaction at approximately 250°C. Improved methods of O₂ scrubbing need to be developed which reduce the amount of heat rejection required.

New methods of controlling the chemical balance of the nutrient solution are being developed using ion exchange. This technology may deliver a maintenance free, long duration pH control. Progress in this area will be monitored for future use.

TECHNOLOGY DEVELOPMENT

Concerns requiring further study and testing:

- Plant vibration sensitivity level
 - The levels of vibration isolation attainable within plant habitat
 - Humidity control and air/water separators
 - Heat transfer at low flow rates
 - Lighting to a min. of 600 $\mu\text{moles}/\text{m}^2/\text{s}$
 - Video camera optics arrangement to provide side viewing of plant
 - High Output LEDs which satisfy the science requirements
- Blue light in the range of 400-500 nm at low photon flux levels
- Current Blue Light LEDs have very low outputs
- Methods of scrubbing excess O_2 without excessive exothermic reaction
 - Volume efficient methods for air/water separation and humidity control.
 - Ion exchange hardware for maintaining nutrient solution balance

SUMMARY

The conceptual design of the Plant Habitat presented in this report meets most of the primary mission requirements. However, due to packaging constraints, the effectiveness of components such as the heat exchanger and air/water separator may be limited. It may prove difficult to meet combinations of requirements. For example, it may be difficult to maintain a 40% humidity level at low air flow rates with a photon flux level of 500 $\mu\text{mole/m}^2/\text{s}$. However, this is considered to be extreme since, for most plant growth experiments, the environment will consist of relatively high humidity air at moderate flow rates and moderate photon flux levels.

Due to volume constraints within the Plant Habitat, isolation from vibrations external to the Plant Habitat may need to be accomplished at the Holding System and Centrifuge. Components within the Plant Habitat such as pumps, motors, valves can be isolated individually for vibration.

Maintaining O_2 levels to 5% for extended periods of time is not possible in this baseline concept. However, if one or two small plant chambers were replaced with an additional O_2 scrubber, experiments with low O_2 levels could be performed.

Commercially available hardware was used in the design when possible, although several components represent state-of-the-art development. The LED array, air/water separator, and O_2 scrubber will require further development to ensure a successful design. Furthermore, efficient packaging represents one of major design challenges to be met.

SUMMARY

Findings of the Plant Habitat study:

- Most primary requirements are met with this concept
- The Plant Habitat is constrained for volume to package the support systems. Efficient component packaging is a primary driver to meeting the requirements
- Requirements for air flow uniformity, temperature control and uniformity, and vibration isolation may be difficult to meet given the size constraints of the Plant Habitat
- Plant experiments operating at standard O₂ levels pose no excessive demands on the Plant Habitat. Lower O₂ limits would require additional O₂ scrubbers

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|--|--|--|---|---|--|
| 1. Report No. NASA TM-102860 | | 2. Government Accession No. | | 3. Recipient's Catalog No. | |
| 4. Title and Subtitle Centrifuge Facility Conceptual System Study Volume I: Facility Overview and Habitats | | | | 5. Report Date October 1990 | |
| | | | | 6. Performing Organization Code | |
| 7. Author(s) Robert Synnestvedt, Editor | | | | 8. Performing Organization Report No. A-90268 | |
| | | | | 10. Work Unit No. 186-30-21 | |
| 9. Performing Organization Name and Address Ames Research Center Moffett Field, CA 94035-1000 | | | | 11. Contract or Grant No. | |
| | | | | 13. Type of Report and Period Covered Technical Memorandum | |
| 12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001 | | | | 14. Sponsoring Agency Code | |
| | | | | | |
| 15. Supplementary Notes Point of Contact: Robert Synnestvedt, Ames Research Center, MS 244-19, Moffett Field, CA 94035-1000 (415) 604-3143 or FTS 464-3143 | | | | | |
| 16. Abstract The Centrifuge Facility Conceptual System Study presents results of a NASA phase-A study conducted from mid 1987 through mid 1989 at Ames Research Center. The Centrifuge Facility is the major element of the biological research facility for the implementation of NASA's Life Science Research Program on Space Station Freedom using non-human specimens (such as small primates, rodents, plants, insects, cell tissues). This report describes five systems which comprise the Facility. 1) Habitats – modular units which house living specimens; 2) Holding Unit – system which supports and supplies resources for habitats in micro-gravity; 3) Centrifuge – system which supports and supplies resources to habitats on a rotating structure to simulate gravitational acceleration; 4) Glovebox – system which provides a closed, controlled environment for experimental procedures on specimens and habitat servicing; 5) Service Unit – system which replaces or cleans specimen chambers. This report is issued in three volumes. Volume I describes Habitats; Volume II describes the Holding Unit, Centrifuge, Glovebox, and Service Unit; and Volume III describes a concept for a larger centrifuge. | | | | | |
| 17. Key Words (Suggested by Author(s)) Centrifuge, Glove box, Artificial gravity, Space science research, Biological research, Space Station payloads | | | 18. Distribution Statement Unclassified-Unlimited Subject Category - 51 | | |
| 19. Security Classif. (of this report) Unclassified | | 20. Security Classif. (of this page) Unclassified | | 21. No. of Pages 356 | |
| | | | | 22. Price A16 | |

